

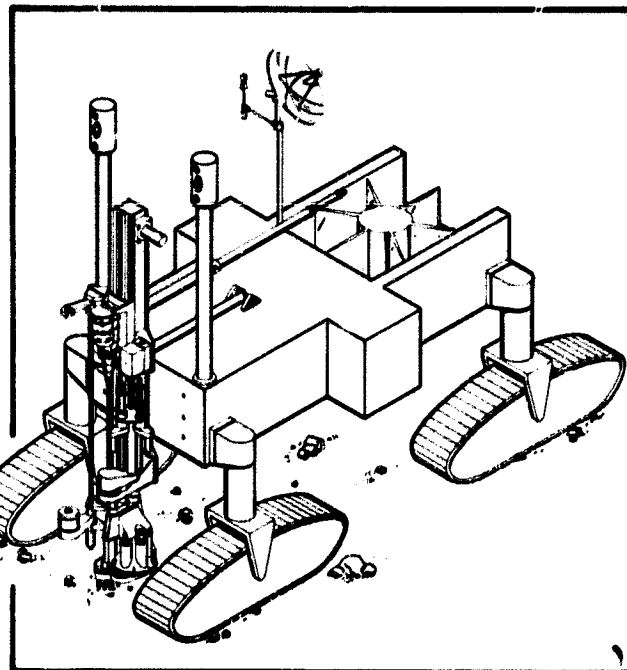
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Final
Report

NASA CR-
160723
April 1980

Study of Sample Drilling Techniques for Mars Sample Return Missions

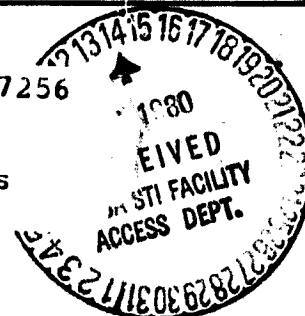


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Prepared for:
National Aeronautics and
Space Administration
Johnson Space Center
Houston, Texas 77058

MARTIN MARIETTA

MCR-79-615 (Issue 3)
Contract NAS9-15907

Final Report

April 1980

**STUDY OF SAMPLE
DRILLING TECHNIQUES
FOR MARS SAMPLE
RETURN MISSIONS**

Prepared for:

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Space Administration
Johnson Space Center
Houston, Texas 77058

MARTIN MARIETTA CORPORATION
DENVER DIVISION
Denver, Colorado 80201

FOREWORD

This report is submitted in accordance with the requirement of NASA Contract NAS9-15907, Article X, Item 2, Final Report. It includes a summary of the work accomplished during the period of performance of the program.

The program was performed under the technical guidance of Dr. Uel S. Clanton of the NASA Johnson Space Center.

The principal Martin Marietta individuals who participated in this study include:

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1.0 INTRODUCTION AND PROGRAM STUDY RESULTS SUMMARY

1.1 Contract Requirements and Schedule

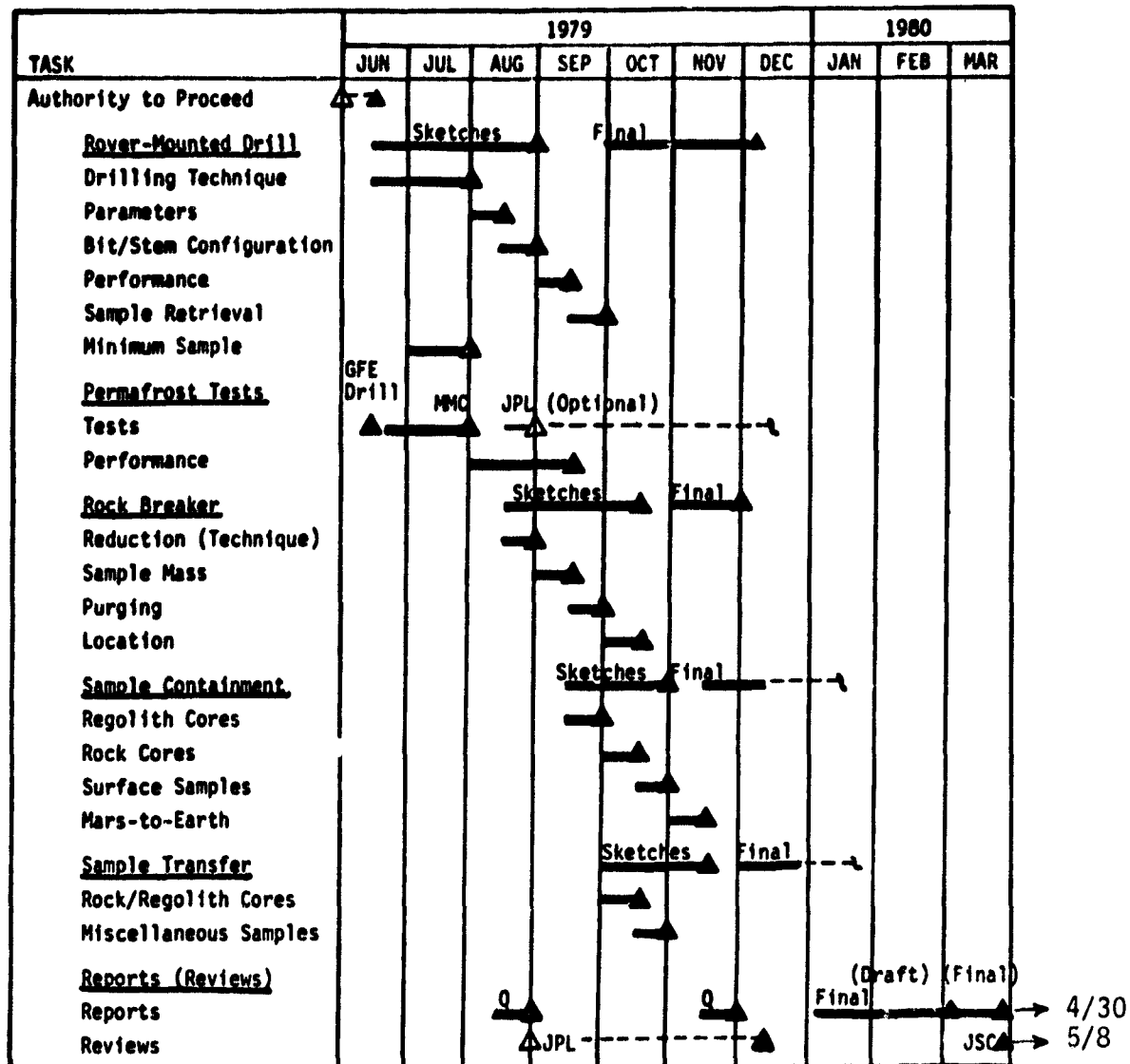
This ten-month study contract with a task value of approximately 10 man-months was initiated on June 12, 1979, and was completed on April 11, 1980. The primary purpose of the study was to perform a series of design and test tasks to demonstrate the feasibility of acquiring various surface samples for a Mars sample return mission. In accordance with NASA direction, the tasks were performed in the order of decreasing priority, i.e., more effort was expended on the first task than the second, etc., with the least effort expended on the last task. The tasks were to be worked and completed in series except where it was obvious that parallel effort would enhance the quality of work. The major tasks of the study included the following:

- 1) Design of a Mars Rover-mounted drill system capable of acquiring crystalline rock cores; prediction of performance, mass, and power requirements for various size systems, and the generation of engineering drawings,
- 2) Performance of simulated permafrost coring tests using a residual Apollo Lunar Surface Drill,
- 3) Design of a rock breaker system which can be used to produce small samples of rock chips from rocks which are too large to return to earth, but too small to be cored with the Rover-mounted drill,
- 4) Design of sample containers for the selected regolith cores, rock cores, and small particulate or rock samples, and,
- 5) Design of sample handling and transfer techniques which will be required through all phases of sample acquisition, processing, and stowage on-board the Earth Return Vehicle.

Although not required by the contract, a preliminary design of a light-weight Rover-mounted sampling scoop was developed. This dedicated sampling scoop could be used in lieu of the JPL-proposed general purpose robotic arm which inherently is more complex to operate and will require a larger percentage of the mass budget for the Rover.

The contract statement-of-work which guided the performance of this study is provided in Appendix A to this report. Table 1-1 provides the milestone schedule for performance of the study.

Table 1-1 Program Milestone Schedule



1.2 Program Summary

1.2.1 Conceptual Design Sketches and Models

The design efforts performed during this study were preceded by the generation of numerous design approach sketches illustrating several potential techniques for accomplishing the desired operations. Additionally, small models of the Mars descent stage, Rover, and associated sample collection and handling hardware were constructed to provide further illustration of the required operations. The resultant sketches and photographs of the models are provided in Appendix C to this report.

1.2.2 Simulated Mars Permafrost Coring

It is anticipated that the Mars sample return mission will involve primarily core drilling and surface sampling in materials (Regolith and Rocks) with physical properties similar to those encountered during the lunar missions (U.S. and Russian) and during the Mars Viking Landers 1 and 2 operations. However, some investigators are also interested in earth-return core samples acquired from the Mars polar regions where subsurface permafrost may be encountered.

A water saturated regolith model was constructed and frozen to a temperature of -80 to -92°C (-62 to -69°F) under earth ambient atmospheric pressure. Coring tests were performed using a residual Apollo Lunar Surface Drill. Penetration rates were extremely slow (2-5 cm/min.) and excessive drilling torques and "freezing" of the drill in the hole were encountered. It is believed that this problem was caused by melting and refreezing of the simulated permafrost material.

It is possible that the drilling of simulated permafrost material under Mars atmospheric pressures may possibly be less difficult due to sublimation of frozen materials. However, additional tests will be required to evaluate that possibility. It is anticipated that a considerable effort will be required to develop a system which will reliably core frozen material from any significant depth (10's of centimeters to meters) in the Mars polar regions.

1.2.3 Rover-Mounted Drill

The general approach used for the Rover-mounted drill system was to develop an autonomous, self-contained design which will provide the capability for drilling in a regolith surface as well as the contractually required crystalline rock. The capability of packaging the rock and regolith samples was also provided with the basic design. This design approach provides an optimum system for the Rover drill; however, the associated weight penalties required for the additional performance must be compared to the expected capabilities of the Rover and the ultimate science objectives for the sample return mission. The weight penalties for the various drill options are provided.

Although the drill design configuration is not "vehicle dependent", a typical integration scheme with the JPL rover configuration was used for purposes of illustration. Top level design configuration drawings were generated.

1.2.4 Rock Breaker System

A lander-mounted rock breaker system was designed which will reduce rocks too small to be cored by the Rover-mounted drill (less than 15 cm) which will be convenient for packing and return to earth. The device basically consists of a sample restraint bin and a spring-loaded hammer

which is capable of delivering sufficient concentrated energy to fracture the candidate earth return rocks.

Design drawings and operational descriptions were generated.

1.2.5 Sample Containment and Handling

Most of the required sample containment and handling features were integrated into the basic design of the Rover-mounted drill. Provisions were made for releasing both the crystalline rock and regolith tubular containers such that they can be transferred to the earth return canister via a lander-mounted robotic arm.

An alternate surface sample handling and packaging system was also designed as an option to the JPL baseline robotic arm. Design drawings and operational descriptions for all sample containment and handling equipment were generated.

2.0 SCIENTIFIC AND ENGINEERING GUIDELINES (SPECIFIED AND DERIVED)

2.1 Core Sampling Guidelines

The major emphasis of this study was directed towards the design of a Rover-mounted crystalline rock drill as required by the Contract Statement of Work provided in Appendix A of this report. A regolith-core drill may also be included on the Mars descent stage vehicle. Although this drill was not included as a study task requirement, considerable emphasis was placed on incorporating a regolith coring capability in the Rover-mounted crystalline rock drill. The inclusion of this capability was based upon the results of a scientific community survey in which the advanced Mars mission sampling "desires" were solicited from 2300 individuals. The results of this scientific community survey was previously reported in another contract report (Ref 25) and is summarized in Appendix B to this report.

A tabulation of design guidelines for both the Rover-mounted and descent stage core drills is provided in Table 2-1. These guidelines include both those addressed in the Contract Statement of Work and others, which were "assumed" if the parameters were not specified.

Table 2-1 Core Drill Sampler Guidelines

PARAMETER	ROVER-MOUNTED DRILL ⁽²⁾	DESCENT STAGE DRILL ⁽¹⁾
1. Surface Material to be Cored	Crystalline Basalt (5-40% Porosity)	Regolith, and Possible Subsurface Permafrost and Rocks
2. Volatiles Containment	N/A	Minimize Escape
3. Sample Contamination	Minimize, including Cross Contamination	Minimize, including Cross Contamination
4. Core Length	10-Centimeter	1-2 Meters
5. Core Diameter	1-Centimeter	2-Centimeters
6. Number of Cores	20-30 (Documented)	3-5
7. Drilling Angle	Vertical and Horizontal to Local Surface	Vertical to Local Surface (Assumed)
8. Power ⁽³⁾	200-300 Watts (15-20 Minutes)	Same as Rover Drill (Assumed)
9. Mass	<25 kg (25 kg Goal for all Rover Sampling Hardware)	Same as for Rover (Assumed)
10. Control	Dedicated Control Electronics Sequenced by Rover Computer	Same as for Rover (Assumed)

NOTES:

- (1) Descent Stage Drill design not required in this study although concepts were developed as illustrated in Appendix C. (See Note 2).
- (2) Rover-Mounted Drill design also includes most of the characteristics desired of the Descent Stage Drill and are directly applicable to a Descent Stage Drill design.
- (3) Radioisotopic Thermal-Electric Generator (RTG) average power expected to be 20-25 watts. The short-term higher drill power consumption will require a storage battery.

2.2 Miscellaneous Equipment Design Guidelines

In addition to the major emphasis task (Rover-Mounted Crystalline Rock Drill) guidelines outlined in Section 2.1, other design guidelines for both contract study items, and non-contract study items were considered for the performance of this study. A summary tabulation of these guidelines is provided in Table 2-2.

Table 2-2 Miscellaneous Equipment Design Guidelines

DESIGN CONSIDERATION ITEM/EQUIPMENT	CRITICAL DESIGN PARAMETERS
1. Rover ⁽¹⁾	Mass: 125 Kilograms (25 kg Target For Sampling) Power: 20-25 Watts Average (RTG) Computer: TBD Available to Sequence All Equipment
2. Rover-Mounted Articulated or Furlable Boom ⁽²⁾	Functions: 1) Acquire Small Rock Samples and Surface Material. 2) Possibly Assist with Transfer of Samples from Drill to Sample Return Container.
3. Descent Stage Contingency Sampler ⁽¹⁾	Functions: 1) Acquire Contingency Samples (If Rover System Inoperable). 2) Possibly Assist with Sample Trans- fer from Rover to Earth Return Vehicle.
4. Rock Breaker System ⁽³⁾	Functions: 1) Reduce Rocks too Small to Core i.e., <15 cm) to Earth Returnable Chip Samples of ≤ 2 cm Size.
5. Sample Containment ⁽³⁾	Containers Required for the Following: (1) Selected Regolith Cores (Hermetic Seal) (2) Selected Rock Cores (Identified Containers) (3) Small Rocks and Surface Particulate (4) Mars-To-Earth Sample Return (2-5 kg)
6. Sample Handling and Transfer ⁽³⁾	Required Through the Following Phases: (1) Transfer of Rock and Regolith Cores to Sample Return Containers. (2) Transfer of Particulate and Small Rock Fragments to Sample Return Container.

NOTES:

- (1) Design not required in this study although concepts were developed as illustrated in Appendix C and in other locations of this report.
- (2) A design was generated although not required by this study
- (3) Designs and design concepts generated in descending order of priority as required by this study.

2.3 Sampling Equipment Location Options

The location of the crystalline rock core drill sampler was specified by the Contract Statement of Work. However, some options did exist for the location of other equipment such as the rock breaker, robotic arm, and simple sample scoop. Additionally, the location of rock core and regolith core "packaging" equipment was also subject to a tradeoff study. In this particular case it was determined that integration of the packaging equipment directly with the core drill was more efficient since many of the packaging operations could make use of the existing drill subsystems such as the translation drive.

Table 2-3 includes a qualitative assessment of the relative advantages and disadvantages for the various equipment location options.

In addition to the brief qualitative assessment of equipment location options, general groundrules were established in regards to single-point failure considerations. These groundrules included the following:

- 1) The rover should include two (2) independent sampling systems - the drill, and either the robotic arm or sampler scoop
- 2) Failure of the electro/mechanical subsystem or electronic control unit for either of the sampling systems should not affect the remaining sampler system (Note: Both control units derive power and commands from rover redundant power subsystem and computer)
- 3) A lander-mounted robotic arm with combination sampler and sample handling end effector to be used as a back-up to a completely failed rover
- 4) Failure of the lander-mounted robotic arm (for sample transfer) must be backed-up by a redundant earth-return canister loading system unless a rover-mounted robotic arm is available.

2.4 Study Tasks

The foregoing paragraphs (2.1, 2.2, 2.3) of this Section established the general scientific and engineering groundrules and guidelines for this study. This "baseline" was used for guidance as the various potential design approaches outlined in Appendix C were examined for applicability towards the final selected design approaches. The results of these study tasks - analyses, design drawings, performance predictions, etc - are presented in the remaining sections of this report. They are presented in the general order of performance and in the order of decreasing priority as specified by the contract Statement of Work.

Table 2-3 Sampling Equipment Location Options

EQUIPMENT	DESCENT STAGE MOUNTED		ROVER-MOUNTED	
	ADVANTAGES	DISADVANTAGES	ADVANTAGES	DISADVANTAGES
Drill-System	1) Mass/Power More Easily Accommodated	1) Extremely Limited Drilling Site	1) Wide Variety of Rock/Regolith Drill Sites	1) High Mass/Power
Rock Breaker	1) Mass/Power More Easily Accommodated 2) Selection of Rocks to Be Crushed Deferred Until All/Most Samples Collected by Rover	1) Examination of Crushed Rocks Via Camera Or Qualitative Instruments Deferred	1) Early Examination of Rocks	1) Mass/Power and Complexity
Robotic Arm	1) Mass/Power More Easily Accommodated 2) More Robotic-Oriented Tasks Required at Lander	1) None	1) More Robotic-Oriented Tasks Can Be Performed Which Otherwise require Auxiliary Equipment	1) Very High Mass and Software Complexity Penalty
Simple Sample Scoop	1) Lower Weight/Power Requirement	1) Auxiliary Equipment Required to Perform the Robotic-Oriented Tasks	1) Lower Mass/Power 2) Less Rover Software	1) Auxiliary Equipment Required To Perform Sample Handling

The following represents the preferred equipment locations:

- 1) Robotic arm on lander to perform Rover-To-Lander, and Lander-To-Earth return canister sample transfer, and to serve as back-up sampler
- 2) Drill-system and simple sampler scoop/sample collector on Rover
- 3) Rock breaker on lander

NOTE: Robotic arms and drills on both lander and Rover are desirable, but are probably not within the mission constraints of Mass, Volume, and Power.

3.0 ROVER-MOUNTED DRILL SYSTEM

3.1 Study Objectives

The Rover-mounted drill system must be capable of producing 10-centimeter length cores from crystalline rock with an equivalent hardness ranging from 5% to 40% porosity basalt. The system must be automated such that it can operate from digital sequence command loads stored in the Rover computer. Control electronics will be required to operate between the computer and the drill system. The specific objectives of this study included the following:

- 1) Assess optimum drilling technique, i.e., rotary-percussion, rotary, impact, ultrasonic, and others,
- 2) Develop appropriate core bit and stem configuration, preferably with a diameter smaller than the Apollo Lunar Surface Drill configuration (i.e., 1.0 vs 1.9 cm core) to reduce drilling energy consumption and the return sample stowage volume requirements.
- 3) Develop a power head configuration using the data from (1) and previous planetary drill experience,
- 4) Using data from (1), (2), and (3), generate predictions of drilling forces, speeds, percussion impact energies, and power requirements vs drill penetration rate, including temperature effects,
- 5) Generate top-level design configuration drawings for the Rover-mounted drill system to include techniques for rock core sample retrieval and a means of restraining small rocks to the surface during coring operations, and,
- 6) Generate data (or matrices) illustrating performance increase versus increases in power and mass for the proposed system.

NOTE: The initial design for the Rover-Mounted Drill System incorporated the capability of acquiring and packaging 1.9 centimeter regolith cores in addition to the contractually specified smaller crystalline rock core requirement.

3.2 Optimum Drilling Technique

Martin Marietta conducted numerous design studies during the 1965-1968 time frame in support of the Apollo Lunar Surface Drill contracts. The results of these studies are reported in References 11 through 21. Several of these studies were directed towards the determination of the optimum drilling technique for the astronaut-operated lunar drills.

Many of the design considerations applicable to the lunar drills (minimum energy consumption, drill stem thrust, core temperature rise, contamination, etc) are also applicable to the automated Mars Rover-mounted drill system. These studies resulted in the selection of a rotary percussion system as being most adaptable to meet the planetary drilling requirements.

More recently, Dr. W. C. Maurer, a senior research specialist at the Esso Production Research Company, published a book entitled, "Novel Drilling Techniques." This publication (Ref 11) reexamines all known drilling techniques, and categorizes many of these techniques with respect to their power consumption operating efficiency. Table 3-1 provides a tabulation of the most applicable commercial drilling techniques and related specific drilling energy. The percussive systems exhibit the most efficient specific energy characteristics.

In addition to the drilling techniques listed in Table 3-1, there exists a somewhat long list of other potential drilling techniques which have been used in earth applications but are considered impractical for the Mars application. These drilling techniques are tabulated in Table 3-2 along with appropriate comments regarding their applicability.

In summary, the updated assessment of drilling state-of-the art techniques most applicable to the Mars Sample Return Mission is summarized in Table 3-3.

Table 3-3 Rotary Diamond and Rotary Percussion

DRILLING TECHNIQUES	ADVANTAGES	DISADVANTAGES
Rotary Diamond	Simpler Mechanization Lighter Weight Good Rock Core Recovery	High Specific Energy-Requirement Requires Bit Coolant Requires High Drilling Thrusts
Rotary Percussion	Lower Specific Energy Requirement No Bit Coolant Lower Drilling Thrusts Good Regolith Core Recovery	More Complex Mechanization Heavier Weight Rock Cores Subject to Fracturing

NOTE: The results of the rotary vs rotary-percussion trade study and tests performed under contract NAS9-3542 are equally valid for the Mars Sample Return Mission as reported in Reference (11).

Table 3-1 Potential Drilling Techniques and Relative Energy Requirements

DRILLING TECHNIQUE	AVERAGE HOLE SIZE (CM)	POWER TO ROCK (HP)	TYPICAL DRILLING RATE (CM/MIN)				SPECIFIC ENERGY (JOULES/CM ³)			
			ROCK TYPE*				ROCK TYPE*			
			SOFT	MEDIUM	HARD	VERY HARD	SOFT	MEDIUM	HARD	VERY HARD
Percussive Jackhammer	3.8	5	Used Only For Hard Rocks		75	50	--	--	260	390
Drifter	4.8	9								
Blaschle	7.6	11	200	100	20	5	--	40	210	840
Rotary (Mining) Roller	20	30								
Drag	10	15	400	200	100	Dulls	20	40	80	--
Diamond	5	10	Not Used		20	5	--	--	1120	4500
Rotary (Oil Field) Roller Drag	20	30	50	10	5	2	80	420	840	2100
Drag	20	50	100	20	Not Used	Used	70	350	--	--
Diamond	20	20	20	5	2	1	140	560	1400	2800
Ultrasonic	1.2	45								
						0.25				19000

*ROCK TYPE	COMPRESSIVE STRENGTH	
	(KG/CM ²)	psi
SOFT	0-500	0-7,112
MEDIUM	500-1000	7,112-14,223
HARD	1000-2000	14,224-28,446
VERY HARD	>2000	>28,446

Data Extracted From Maurer, W. C., Novel Drilling
Techniques, 1969

Table 3-2 Other Potential Drilling Techniques

DRILLING TECHNIQUE	COMMENTS
<p>Mechanically Induced Stresses</p> <ul style="list-style-type: none"> Turbine Drills Pellet Drills Continuous Penetrators Implosion Drills Spark Drills Electrohydraulic Crushers Explosive Drills Erosion Drills 	<p>Not Practical for Small Diameter Holes-No Core Requires Fluid Pellet Accelerator-No Core Requires Excessive Forces (3-15,000 Kg/Cm²) Requires an Atmosphere for Operation Requires Gas or Fluid for Energy Transfer Requires Fluid for Energy Transfer Produces Contamination-No Core Requires Open Loop Gas or Fluid for Energy Transfer</p>
<p>Thermally Induced Stresses</p> <ul style="list-style-type: none"> Jet-Piercing Drills Forced-Flame Drills Electric Disintegration Drills Terra-Jetten Drills High Frequency Electric Drills Microwave Drills Induction Drills 	<p>All Thermal Techniques would Result in Severe Alteration of Mars Subsurface Samples</p>
<p>Fusion and Vaporization</p> <ul style="list-style-type: none"> Electric Heater Drills Nuclear Drills Electric Arc Drills Plasma Drills Electron Beam Drills Laser Drills 	<p>All Fusion Techniques would Result in Severe Alteration of Mars Subsurface Samples</p>
Chemical Methods	Liquid Chemicals Impractical for Mars Application

3.3 Core Bit and Stem Configurations

Figure 3-1 illustrates the core bit configurations for both the crystalline rock and regolith coring operations.

The rock core bit is similar in configuration to the Apollo Lunar Surface Drill Bit except it has been scaled down to produce a smaller diameter (1.0 vs 1.9 cm) core. This reduction in diameter, combined with a further reduction (0.330 vs 0.356 cm) in the cutting kerf results in a reduced cutting area from the original 2.529 cm² to 1.381 cm². This reduction in cutting annulus will theoretically result in 54.6% less energy consumed for the same drilling rate compared to the original lunar drill bit. Further reduction in cutting kerf may be possible; however, the potential of fracturing poorly supported cutters cannot be easily assessed without fabrication and test of breadboard hardware. The cutters are fabricated from tungsten carbide with an RA hardness of approximately 90.

The rock core bit incorporates a metallic core retainer to preclude loss of the 10-centimeter cores during the withdrawal process. It is expected that the core will fracture at the parent rock interface due to the small diameter of the bit; however, this must be evaluated by test. Removal of the core from the core bit is automatically accomplished by the core removal mechanism described in Paragraph 3.6. Basically, the core is removed by a plunger which forces the core through the back end of the bit.

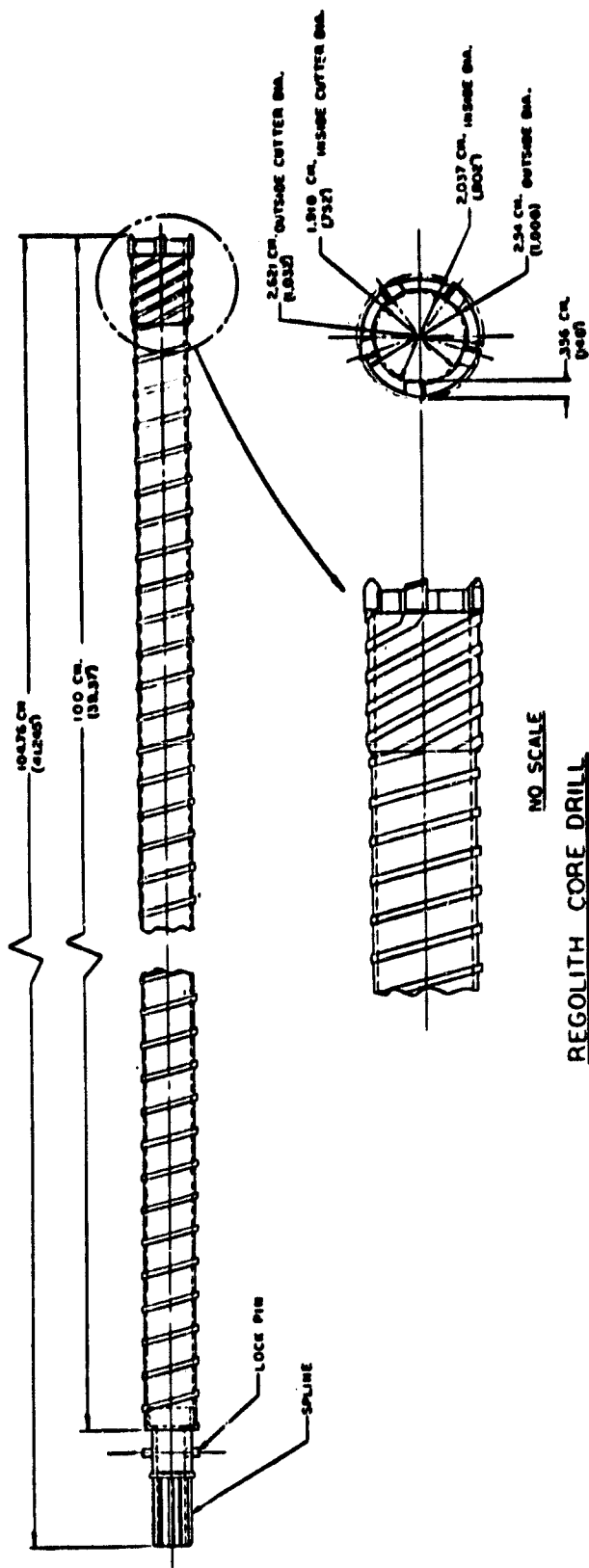
The 1-meter regolith core bit retains the approximate dimensions of the lunar drill, i.e., a 1.9 cm diameter core. The larger diameter is retained to ensure proper "flow" of regolith up the tube during the coring process. The area of the cutting annulus is much less influential on power consumption when coring in regolith as compared to rock. No core retainer is required for restraining the cohesive regolith.

Helical flutes are machined on the outer surface of both configurations to provide for the transport of cuttings generated by the core bit carbide cutters to the upper surface of the drilled hole.

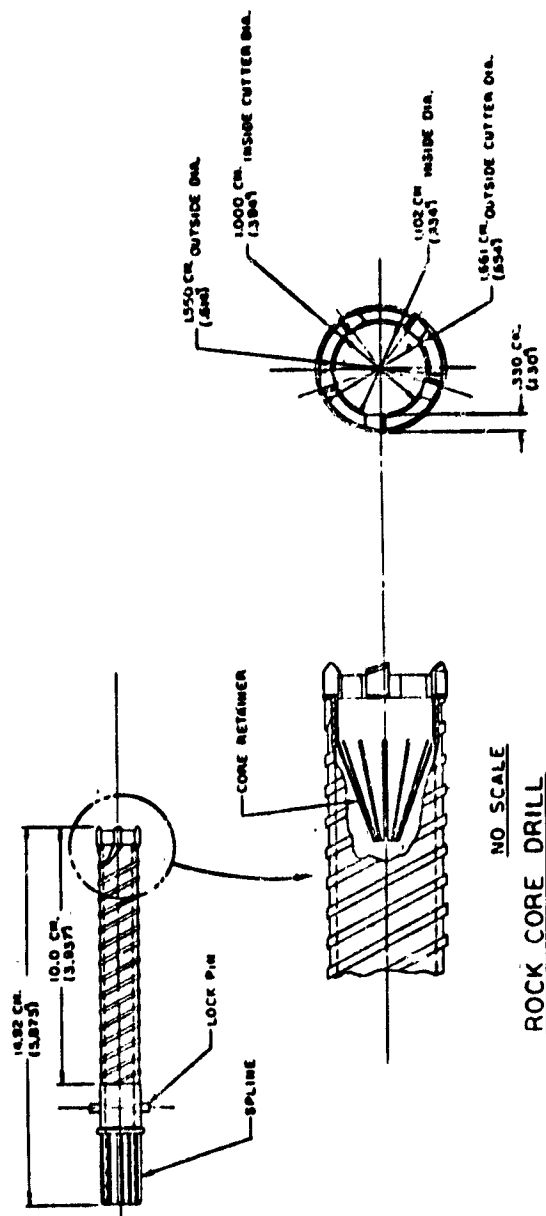
3.4 Power Head Configuration

The Apollo Lunar Surface Drill (ALSD) power head was used as a baseline for the Rover-mounted drill, scaling factors were also used to predict operational performance for systems smaller than the ALSD power head as described in Paragraph 3.5.

Figure 3-2 illustrates the power head configuration. Basically, the device includes an electric motor, a core bit rotation system, and a linear percussion system. Operation of the motor results in rotation of the output drive "spindle" through a 2-stage gear reduction and a ball-spline rotary drive. Operation of the motor also rotates a cam gear which



NO SCALE
REGOLITH CORE DRILL



NO SCALE
ROCK CORE DRILL

Figure 3-1 Crystalline Rock and Regolith Core Bit and Stem Configurations

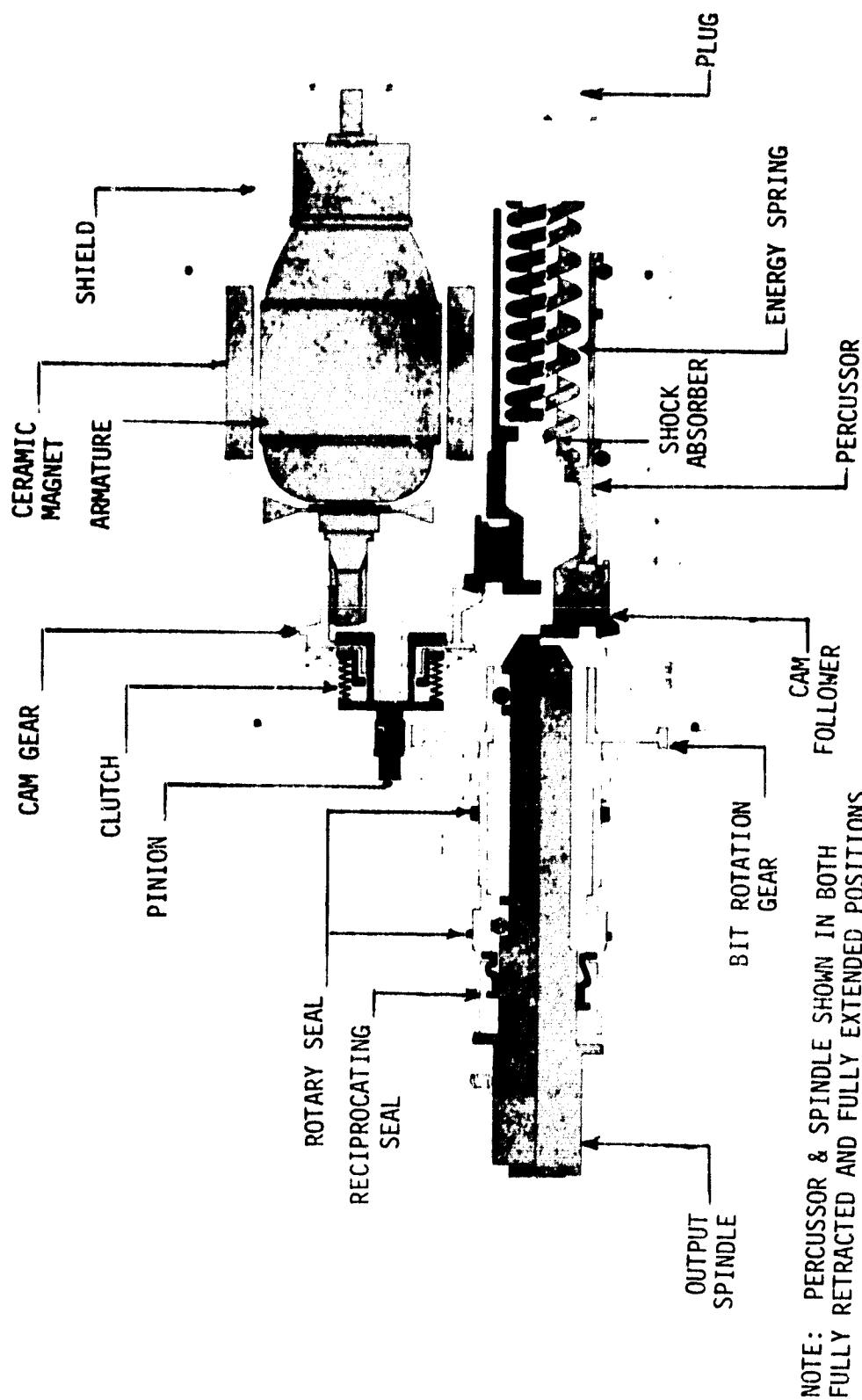


Figure 3-2 Power Head Configuration

provides a lift-force via a ball bearing supported cam follower, to compress the percussive energy spring. When the cam lobe crest passes under the cam follower, the spring energy is released thus accelerating the cam follower towards the output drive spindle. The stored percussive energy is transferred to the core bit via the cam-follower "hammer" striking the output drive spindle which is mechanically coupled to the core bit stem. The operating characteristics of the baseline power head are illustrated in Figure 3-3.

3.5 Drilling Performance Predictions

The drilling rate predictions were initially based upon the baseline ALSO power head without scale-down. Figure 3-4 illustrates the penetration rate and specific energy requirements for the ALSO 1.9 centimeter diameter core bit when operating in a typical 5% porosity basalt at various levels of operating thrust. It should be noted that the specific energy reaches an optimum (minimum) at a thrust of approximately 32 kilograms which infers ideal transfer of rotary-percussive energy to the rock surface. Thrust levels below the 32 kilogram optimum result in increasingly inefficient transfer of percussive energy to the rock, and thrusts higher than the optimum result in excessive rotary forces tending to overload the power head.

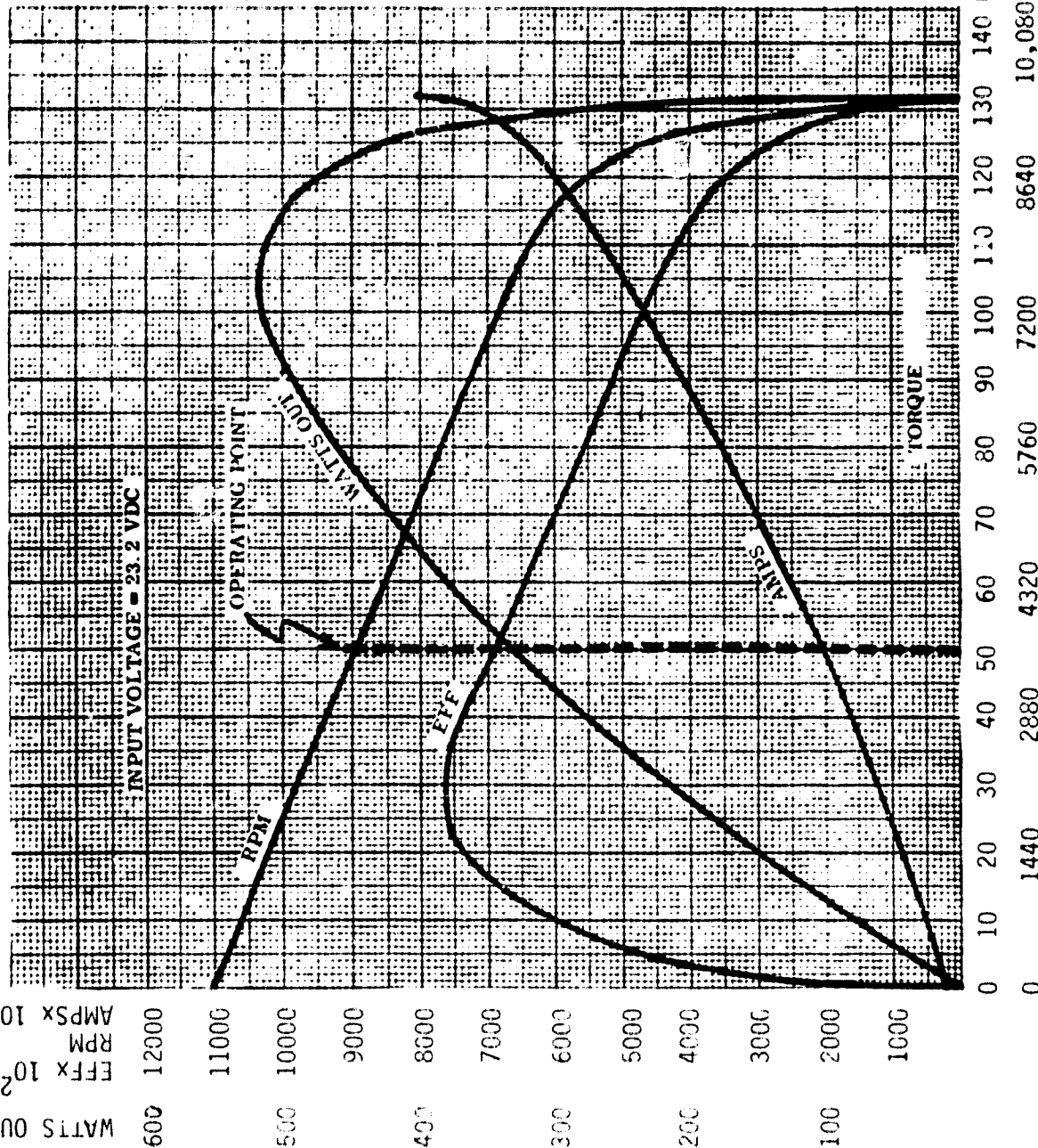
Figure 3-4 also illustrates the predicted performance of the 1.0 centimeter diameter core bit (described in Paragraph 3.3) using the same baseline power head and energy expenditure. It is possible that the optimum (minimum) energy thrust value may shift to the left (Lower optimum thrust value) but this must be verified by test. The significance of this optimum thrust is that its value may be higher than that which can be restrained by the 125 kilogram rover operating in a 3/8-G planetary environment. It can be calculated that approximately 23.4 kilograms is the maximum available restraining force for the drill mounted in the front end of the Mars rover. Higher restraining forces would be available if it were practical to mount the drill near the center of gravity of the rover.

Table 3-4 provides a tabulation of the expected performance of the 1.0 centimeter diameter core bit operating in 5% and 40% porosity basalt, and the 1.9 centimeter diameter core bit operating in dry regolith. The table includes predictions for the baseline ALSO (System No. 1) and for systems that are scaled down 25% (System No. 2) and 50% (System No. 3) from the baseline. The scaling factors also include predictions of power head motor and gear train operating efficiencies.

Note: A summation of the power operating requirements and recommendation rover power system is provided in a subsequent section of this report.

MOTOR PERFORMANCE

TYPICAL PARAMETERS



MOTOR

VOLTS-23.2 V.
CURRENT-20.0 A.
PWR. IN-464 W.
SPEED-9000 RPM
EFFICIENCY-70%

PERCUSSION SYSTEM

CAM-1.30" (0.5 IN.), 14°
SPRING-42.9 KG/CM (240LB./IN.)
PERCUSSION MASS-0.3KG (0.66LB.)
ENERGY/BLOW-44.9CM-KG (39 IN.-LB.)

POWER TRAIN

MOTOR-TO-ROTARY DRIVE-33.1
MOTOR-TO-CAM DRIVE-4.1
BLOWS/BIT REVOLUTION-8.1
NOMINAL BIT SPEED-272RPM
NOMINAL PERCUSSION RATE-2195BPM

Figure 3-5 Power Head Characteristics

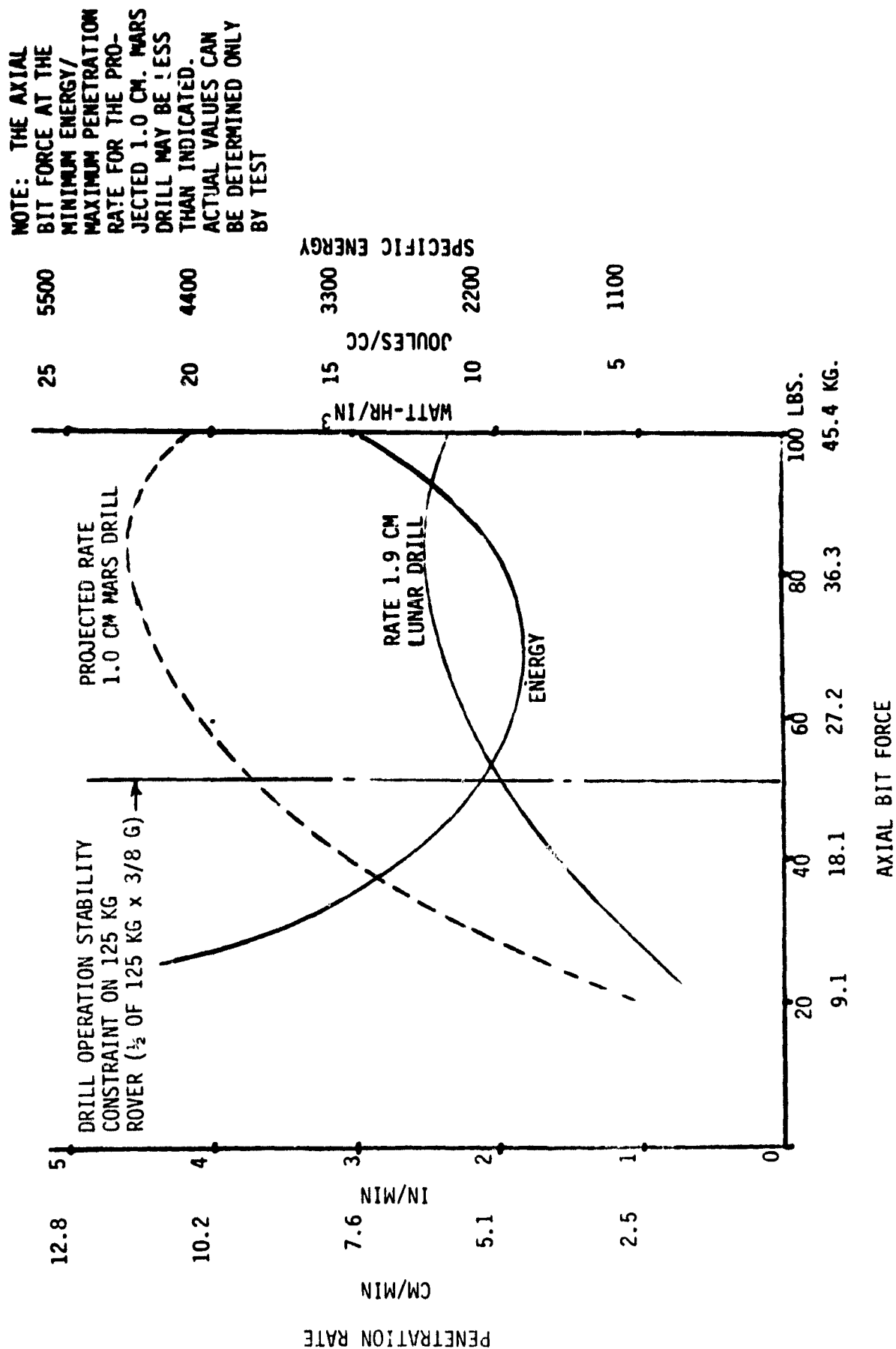


Figure 3-4 Projected Rover-Mounted Core Drill Performance (5% Porosity Basalt)

Table 3-4 Mars Core Drill Performance Scaling

DRILLING MATERIAL (CORE SIZE)	SYSTEM NO. 1	SYSTEM NO. 2	SYSTEM NO. 3
	DRILL RATE CM/MIN *	DRILL RATE CM/MIN *	DRILL RATE CM/MIN *
5% POROSITY BASALT (1 CM CORE)	11	8	5
40% POROSITY BASALT (1 CM CORE)	33	24	16
DRY REGOLITH (1.9 CM CORE)	100	75	50

POWERHEAD EFFICIENCY

* NOTE: INDICATES
MAXIMUM PENETRATION RATE
UNDER IDEAL AXIAL BIT LOAD-
ING CONDITIONS. ACTUAL MARS
DRILLING RATES MAY BE
REDUCED 25-50 %.

INPUT POWER

MOTOR (70)

1st GEAR STAGE (95)

2nd GEAR STAGE (95) PERCUSSION CAM (65)

ROTARY OUTPUT (63.2)

PERCUSSION OUTPUT (56.5)

POWER REQUIREMENTS
DISTRIBUTION

	SYSTEM NO. 1	SYSTEM NO. 2	SYSTEM NO. 3
	WATTS	WATTS	WATTS
TOTAL INPUT POWER	473	354	236
MOTOR LOSS	142	106	71
1st GEAR STAGE LOSS	17	12	8
2nd GEAR STAGE LOSS	6	5	3
PERCUSSION CAM LOSS	28	21	14
DELIVERED ROTARY ENERGY	120	90	60
DELIVERED PERCUSSIVE ENERGY	160	120	80

NOTES: 1) INCREASES IN CORE BIT ROTATION DOES NOT SIGNIFICANTLY IMPROVE PENETRATION RATE. POTATION MUST BE SUFFICIENT FOR CUTTINGS REMOVAL AND OPTIMIZED FOR CARBIDE CUTTER INDEXING.

2) SAMPLE TEMPERATURE RISE IS DIFFICULT TO PREDICT - IT IS ESTIMATED THAT THE TEMPERATURE OF DRY REGOLITH CORES (WHICH ARE DRILLED AT RELATIVELY RAPID PENETRATION RATES) MAY INCREASE SEVERAL DEGREES; THE TEMPERATURES OF HARD ROCK OR PERMAFROST CORES (WHICH ARE DRILLED AT RELATIVELY SLOW PENETRATION RATES) MAY INCREASE SEVERAL TENS OF DEGREES.

It may be possible to scale down the baseline power head to values lower than 50%, but this would not be recommended without development hardware test data to validate the predictions. Experience with drill system performance in hard rock drilling has shown that the delivered energy must be above a "threshold minimum" or the system will fail to penetrate the rock.

3.6 Rover-Mounted Drill System Design Configuration

3.6.1 Design Approach

The general approach used for the Rover-mounted drill was to generate a design for a totally self-contained automated system which would collect rock and regolith core samples, deposit and package the samples for return to earth. This all encompassing design exceeds the statement of work requirement which states that rock core samples will only be collected by the Rover drill system. It was concluded that the inclusion of a regolith sample collection capability at this time would provide a good baseline for future study. The addition of regolith sampling can be evaluated based on weight and power penalties and cost as compared to increased mission value. Additionally, if regolith sampling is relegated to the lander vehicle only, the regolith mechanism designs shown in this report can be applied to the lander vehicle.

Although the drill design configuration is not "vehicle dependent", a typical integration scheme with the JPL Rover configuration was used for purposes of illustration. Minor "liberties" were taken with the JPL configuration which included the following:

- 1) The radioisotope thermal-electric generator (RTG) was lowered below the level of the Rover "deck" to provide stowage space for both the drill and the JPL baseline Remote Manipulation System (Robotic Arm).
- 2) The two imaging cameras were moved outboard and forward for equipment clearance purposes.
- 3) The remote manipulator arm was relocated to provide a more optimum stowage.

The Martin-Marietta design for the recommended "Rover Core Drill Collection System" is described in a series of drawings beginning with the top level configuration and continuing down through the various subsystems. Table 3-5 provides a listing of the design drawings. The drawings are provided in Appendix D to this report. A brief description of each subsystem is provided in the following paragraphs of this section.

Table 3-5 Rover-Mounted Drill Drawing List

DRAWING NUMBER	TITLE
MSR-100000	Rover Core Drill Collection System-General Arrangement
MSR-100100	Core Drill Positioning System (CDPS)
MSR-110000	Core Drill Collection System (CDCS)
MSR-110100	Regolith and Rock Core Drills
MSR-120000	Rock Core Handling System (RCHS)
MSR-120100	Rock Core Sample Container and Release Mechanism
MSR-120200	Rock Core Drill Exchange Mechanism
MSR-130000	Regolith Sample Handling System (RSHS)
MSR-130100	Regolith Sample Collection Tube Procedure

3.6.2 Rover Core Drill Collection System (CDCS) - General Arrangement
(Dwg. MSR-100000 - Figure 3-5)

This drawing (Ref. Appendix D) illustrates the following:

1. The overall configuration "stowed" and deployed on the Rover
2. The core drill positioning system

The Core Drill Collection System (CDCS) is mounted on the centerline of the rover and is shown in the stowed position. It will be deployed after landing and not returned to the stowed position. Deployment is accomplished by either the lander-mounted or rover-mounted remote manipulator. No self-contained deployment drive is provided because it is only a one-time operation and the weight penalty for such a drive would not be warranted. The transfer arm attaches to the (CDCS) and the rover. As the manipulator raises the CDCS up and forward, the transfer arm rotates thru 180° to full deploy position. The CDCS is still horizontal (and forward) after deployment and the transfer arm has engaged the Core Drill Positioning System (CDPS) as shown in drawing MSR-100100.

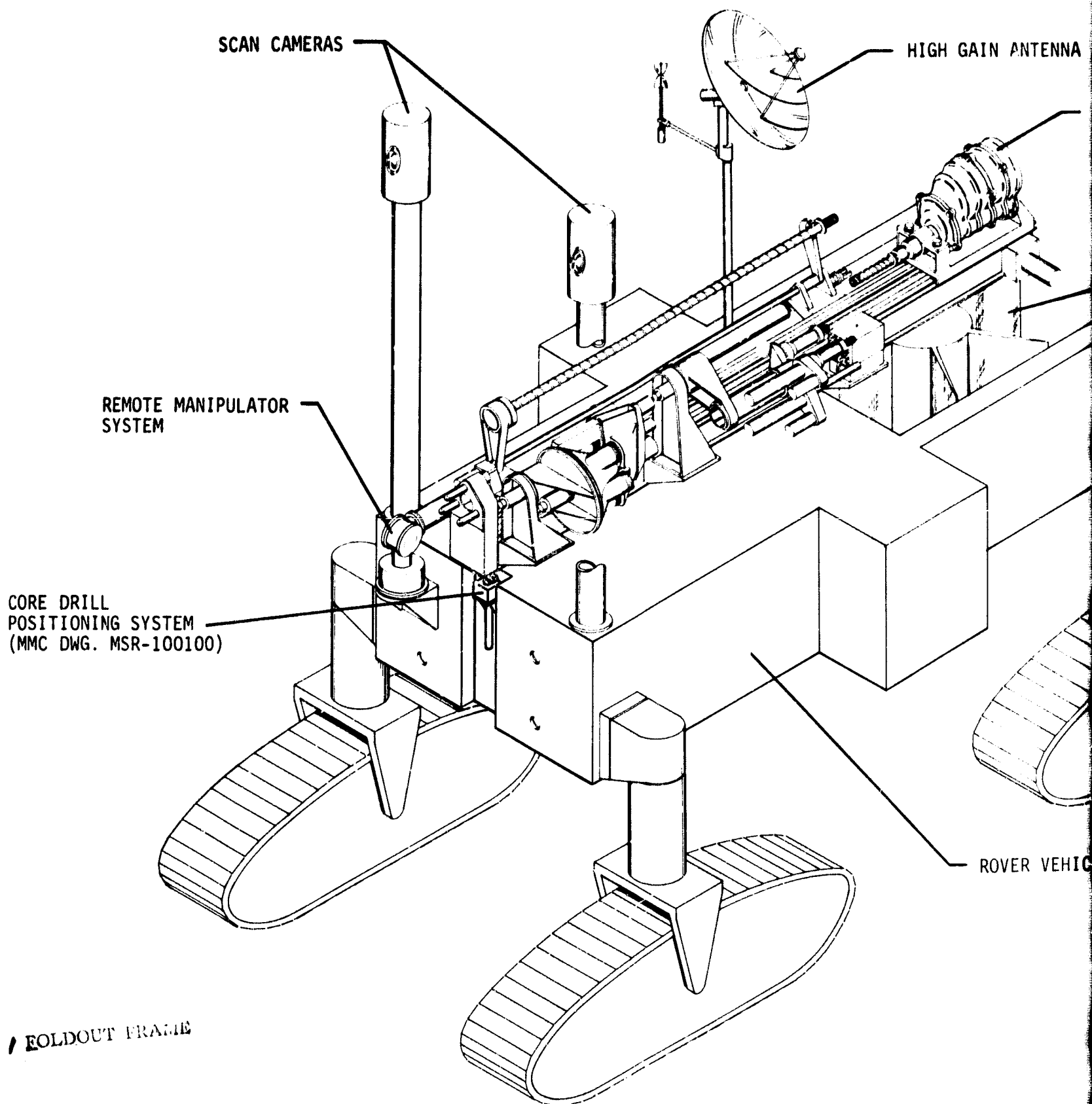
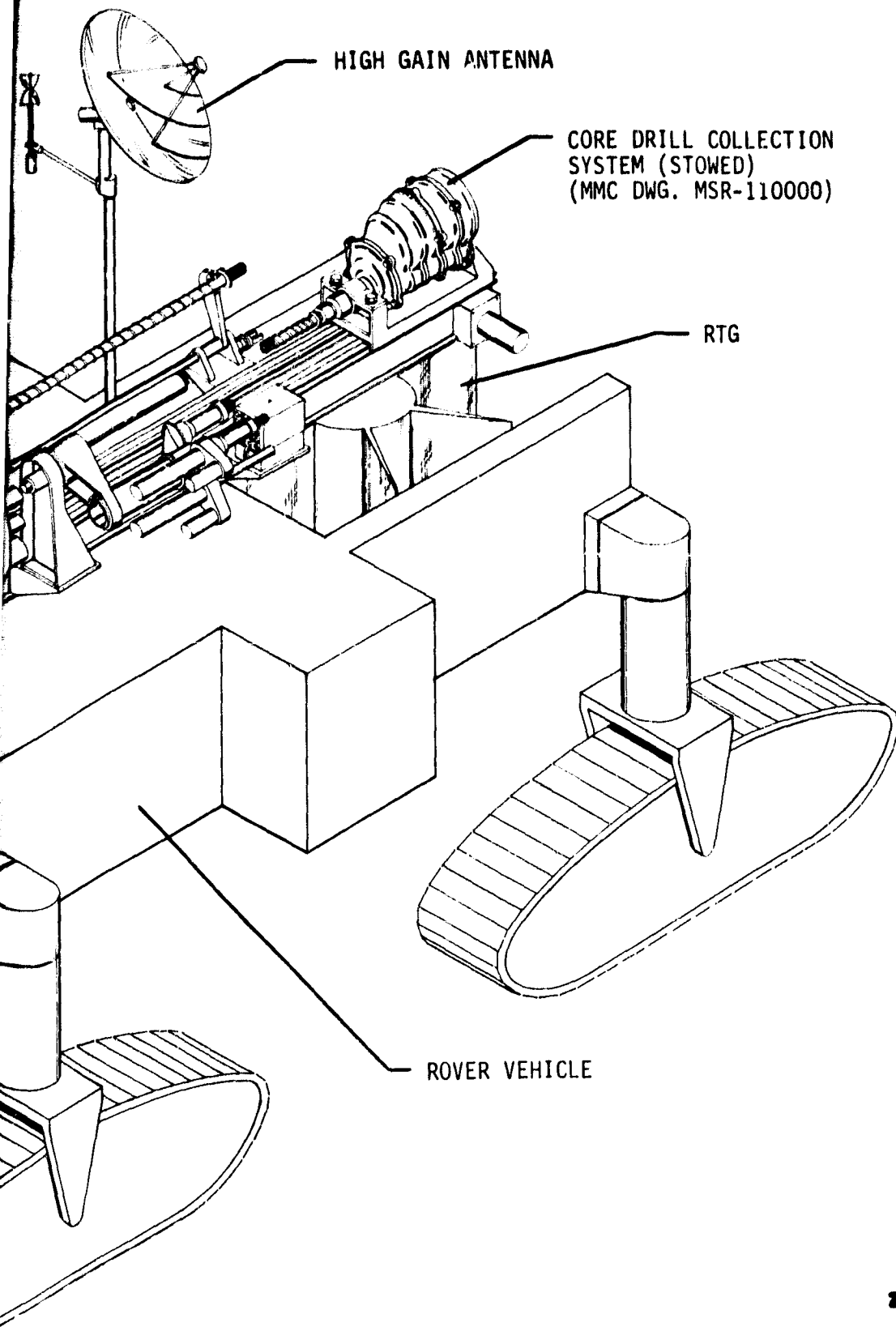


FIGURE 3-5(a) ROVER CORE DRILL COLLECTION SYSTEM-STOWED (REF MSR-100000)



MSR-100000)

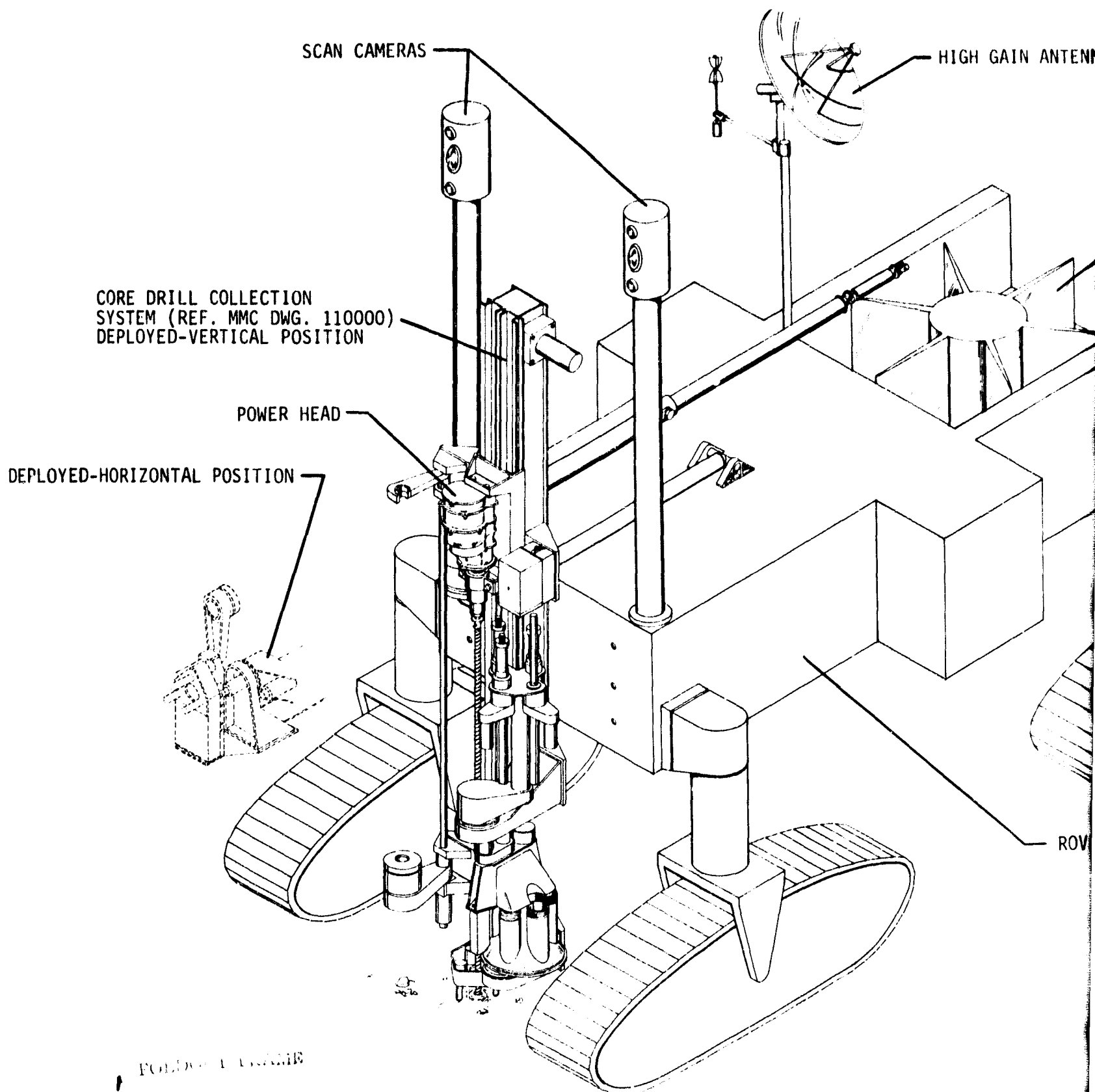
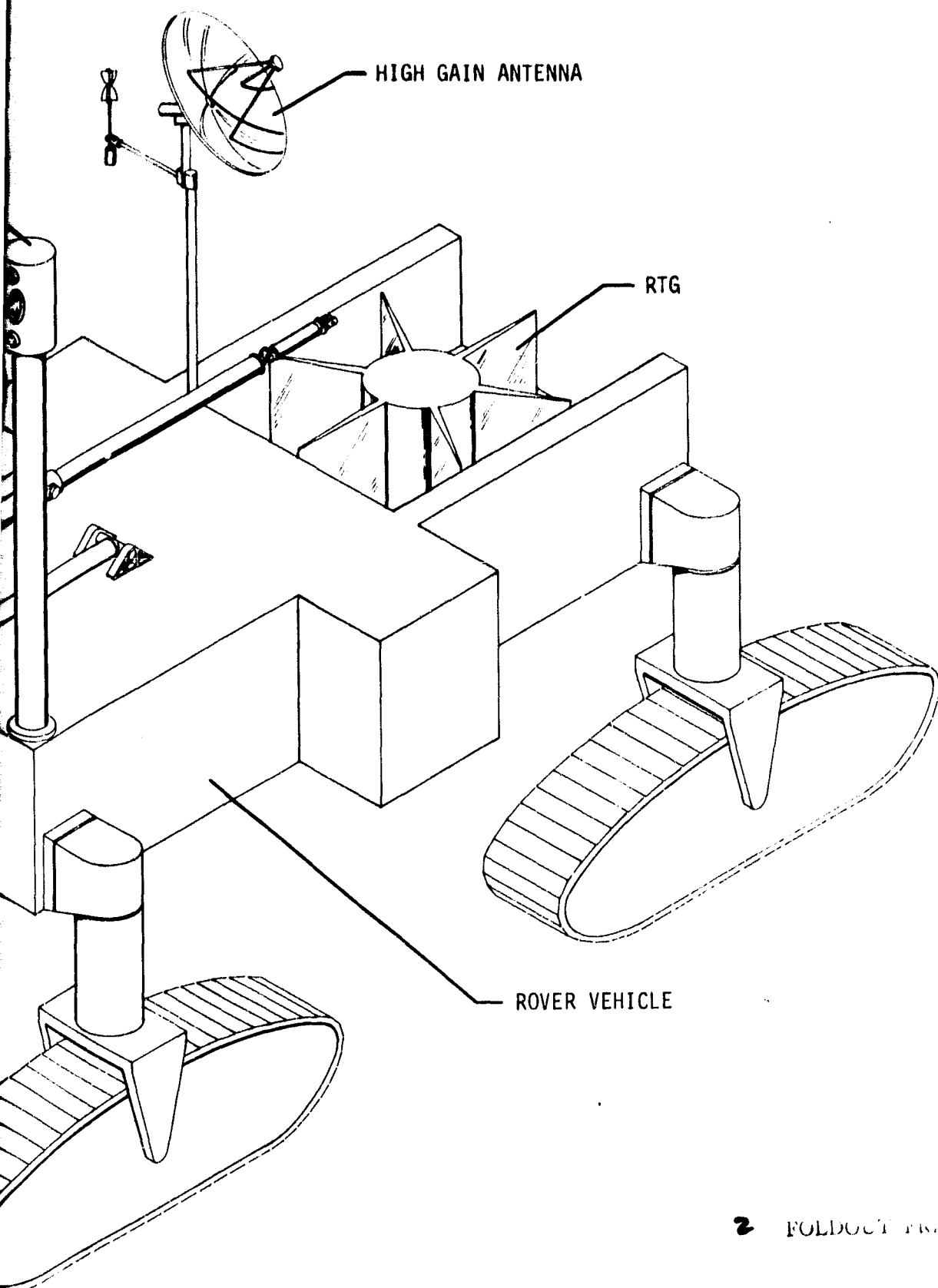


FIGURE 3-5(b) ROVER CORE DRILL COLLECTION SYSTEM-DEPLOYED (REF MSR-100000)



2 FOLDOUT FRAME

Section A-A of MSR-100100 illustrates the latching operation. The spring latch consists of two opposing lightly spring-loaded latches with tapered faces. As the transfer arm drops down on the latch, automatic, non-reversible latching occurs. This operation also ties the transfer arm and CDCS to the positioning system.

The Core Drill positioning system performs two functions.

- 1) Provides the pivot motion to the CDCS.
- 2) Provides 20 centimeters (8 in.) of vertical movement to the CDCS.

The pivot motion allows the CDCS to operate thru 90° . Core samples can be taken from rocks with the drill adjustable to any angular position ranging from vertical to horizontal to the local surface. The vertical movement is necessary to accommodate irregular surface variations and to apply downward force to the drilling surface. This accomplishes two things. 1) It stabilizes the CDCS making a more steady platform for drilling and 2) Small ground rocks can be held in place while drilling takes place. The elevation drive (JM05 Simplex Uni-Lift) is capable of applying up to 225 Kg (500 lbs) of force which is equivalent to the mass of the rover. If the core drills should become jammed, this high retraction force is available for drill extraction.

3.6.3 Core Drill Collection System (CDCS) (Dwg MSR-110000 - Figure 3-6)

The CDCS is a totally integrated system designed to automatically drill, process and store rock and regolith samples while being transported on the Mars Rover vehicle. It requires no assistance from other equipment except for the transfer of the sealed sample containers to the return vehicle.

This drawing (Reference Appendix D) illustrates the following:

- 1) Primary support structure and track
- 2) Power head and carriage
- 3) Carriage drive mechanism
- 4) One meter drill exchange mechanism
- 5) Rock core and drill handling system
- 6) Regolith sample handling system
- 7) Rock core sample container
- 8) Rock support mechanism

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1
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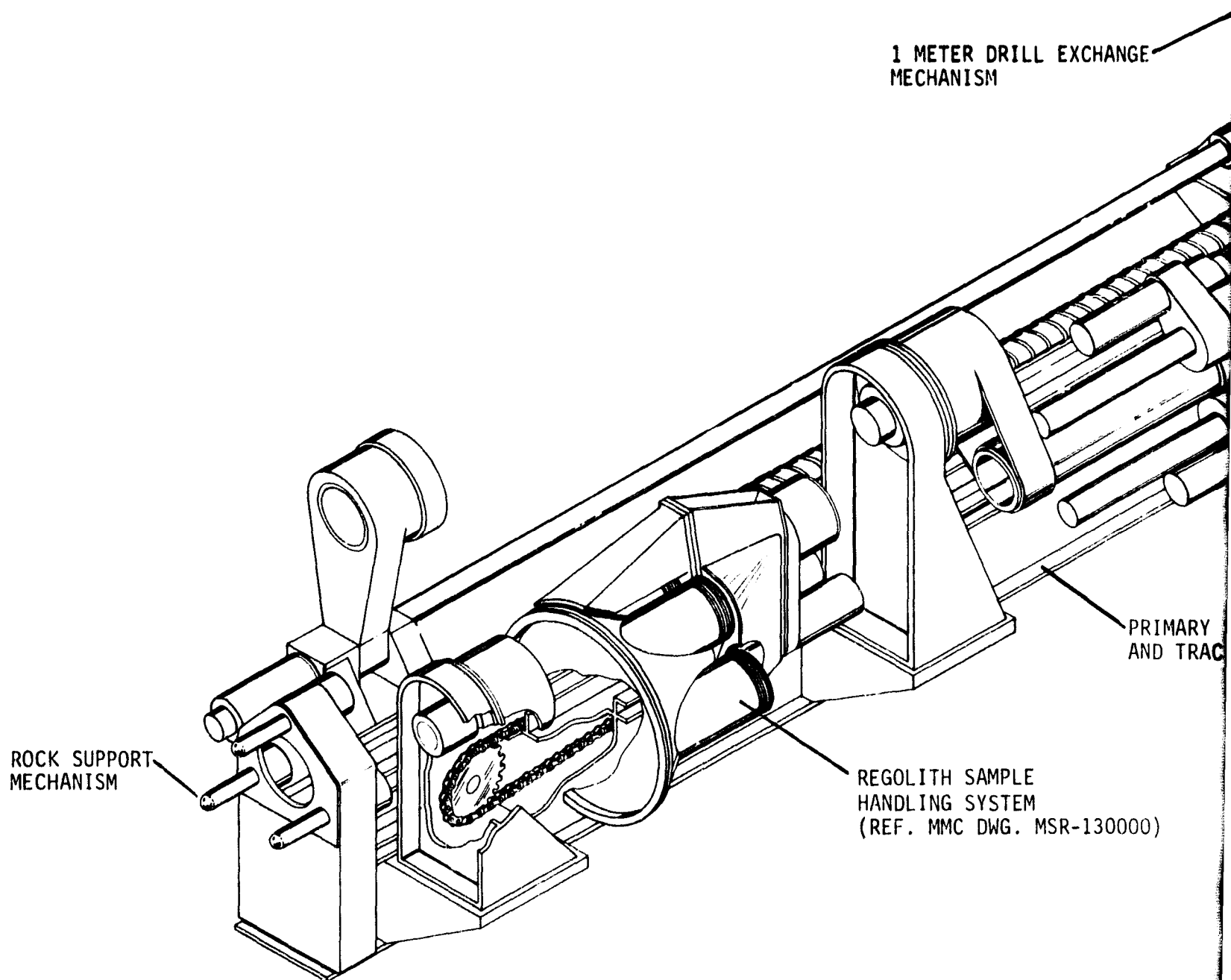
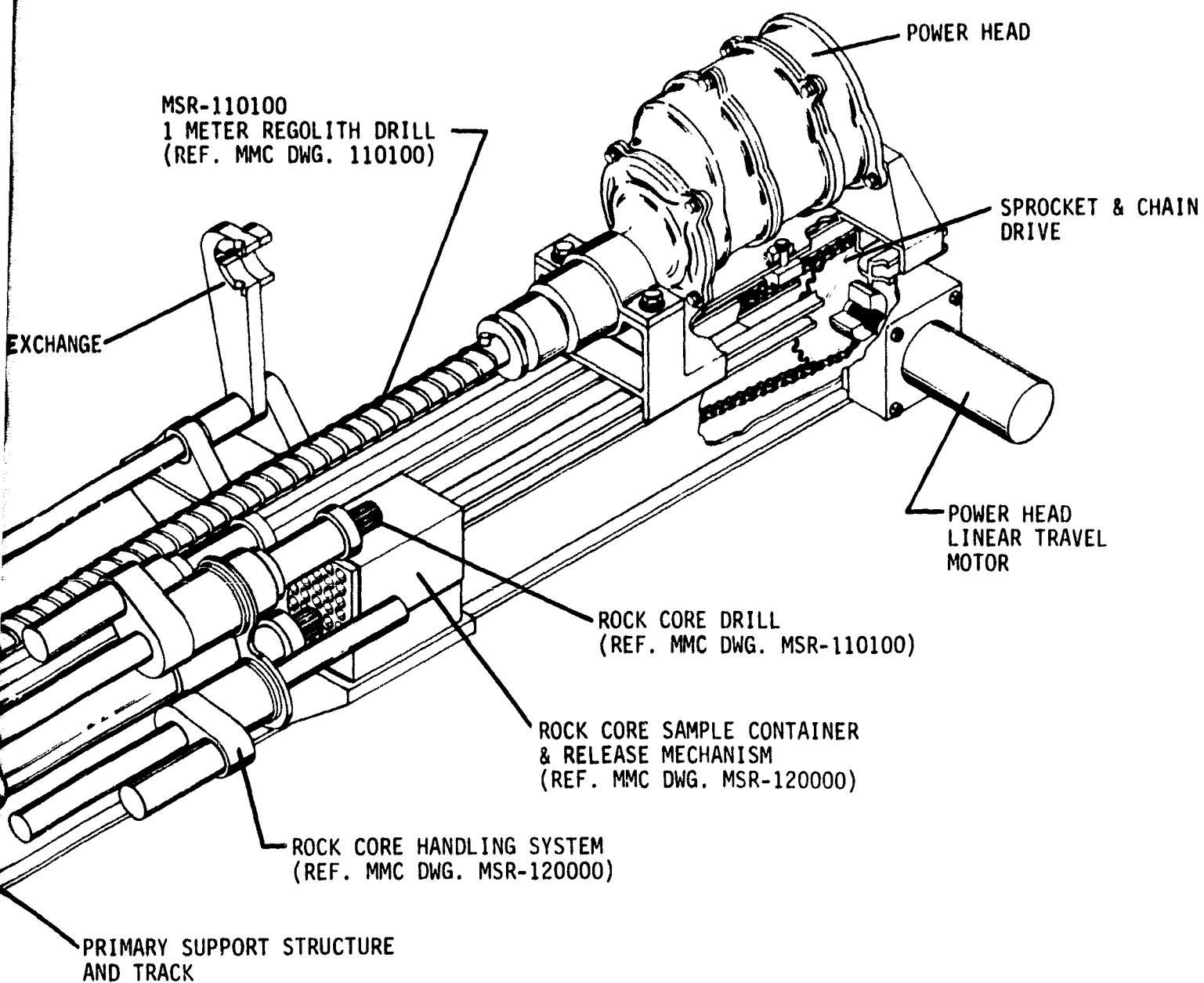


FIGURE 3-6 CORE DRILL COLLECTION SYSTEM (REF MSR-110000)



SR-130000)

FOLDOUT FRAME

Combining these systems on one support structure eliminates the problem of multiple interfaces with the Rover and facilitates the alignment of each system to the power head center line. The design description and function of each element includes the following:

- 1) Primary support structure - This structure is essentially a square tube with the integrated power head track. It will be one piece construction except for the base cover plate. Overhanging brackets will support the various mechanisms where necessary.
- 2) Power head and carriage - This assembly consists of the power head mounted on a carriage which is supported by six cam rollers. The power head is similar in function to the Lunar Drill with the following modifications: 1) It is made reversible for the purpose of drill exchange. The impact function will be eliminated when the drill is operating in reverse. 2) The nose piece is modified to accommodate the new drill attach configuration.
- 3) Carriage drive mechanism - This is a chain drive terminating under the power head carriage. A spring loaded sprocket arm near the center of the support structure prevents chain slack from occurring. The low speed, high torque gearmotor drives the sprocket which translates the power head carriage. A total of 135 Cm (53 inches) of power head travel is available.
- 4) One meter drill exchange mechanism - This mechanism is patterned after the 10 centimeter drill exchange mechanism as described in drawing MSR-120200. The differences are that this drill is one meter in length and larger in diameter. Section B-C shows that the power head end is open on one side. This is to allow drill removal without the one meter withdrawal travel.
- 5) Rock Core and drill handling system - This system is described in drawing MSR-120000. It is shown in the retracted position, clear of the power head travel envelope.
- 6) Regolith Sample Handling System - This system is described in drawing MSR-130000. It is also shown in the retracted position.
- 7) Rock Core Sample Container - This system is described in drawing MSR-120100. Note its location with respect to the rock core handling system.
- 8) Rock Support Mechanism - It may be desirable to drill rock cores from a small rock which is too small to drill without restraining the rock. The three heavily spring loaded pins in this mechanism will bear on the unsupported rock as the vertical drive of the CDCS positioning system drives the CDCS onto the rock to be drilled. The three pins will accommodate any surface irregularities. It also serves to support the CDCS during surface drilling.

This design was developed based upon the use of existing (non-qualified) gearmotors. It was expedient and it will be useful if engineering test equipment is to be built to evaluate feasibility prior to flight hardware go ahead. These selections are listed in Table 3-6 below along with rates and forces available from each drive.

Table 3-6 Rover-Mounted Drill Subsystem Drive Forces and Rates

Subsystem	Force Capability	Operating Rate
Power Head Translation Drive	142 Kg (314 Lbs)	42 cm/min/16.5 in./min)
Elevation Drive	227 Kg (500 Lbs)	30 cm/min (12 in./min)
CDCS Pivot Drive	2.3 M-Kg (200 In.-Lbs)	3.2 RPM
Ball Screw Drives	372 Kg (820 Lbs)	3 cm/min (1.2 in./min)
Turret and Pivot Drives	0.5 M-Kg (40 In.-Lbs)	8.3 RPM

3.6.4 Regolith and Rock Core Drills (Dwg MSR-110100)

This drawing (Ref Appendix D) illustrates the following:

- 1) 1.9 cm I.D. x 1-meter Regolith Core Drill
- 2) 1.0 cm I.D. x 10-cm Rock Core Drill with retainer

A description of these drills is provided in Paragraph 3.3.

3.6.5 Rock Core Handling System (RCHS) (Dwg MSR-120000 - Figure 3-7)

The RCHS is designed to accomplish all tasks necessary in the collection and packaging of rock core samples. This drawing (Ref Appendix D) illustrates the following:

- 1) Drill storage and drill replacement
- 2) Positioning of full and empty drills for the purpose of core removal, power head drill replacement, and sample container capping.
- 3) Capping of sample container.
- 4) Positioning of the mechanism to allow free full linear travel of the power head during drilling operations.

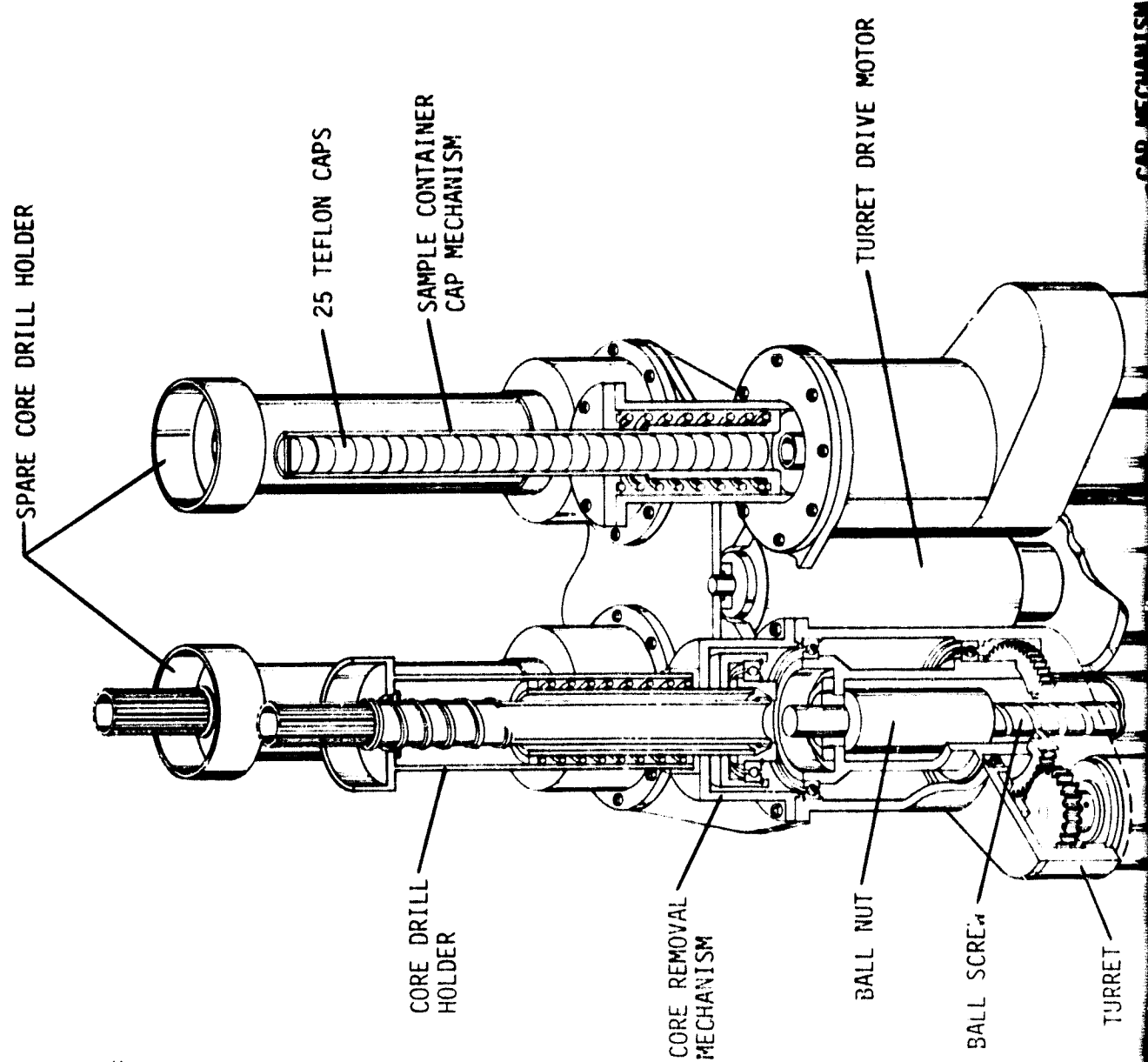
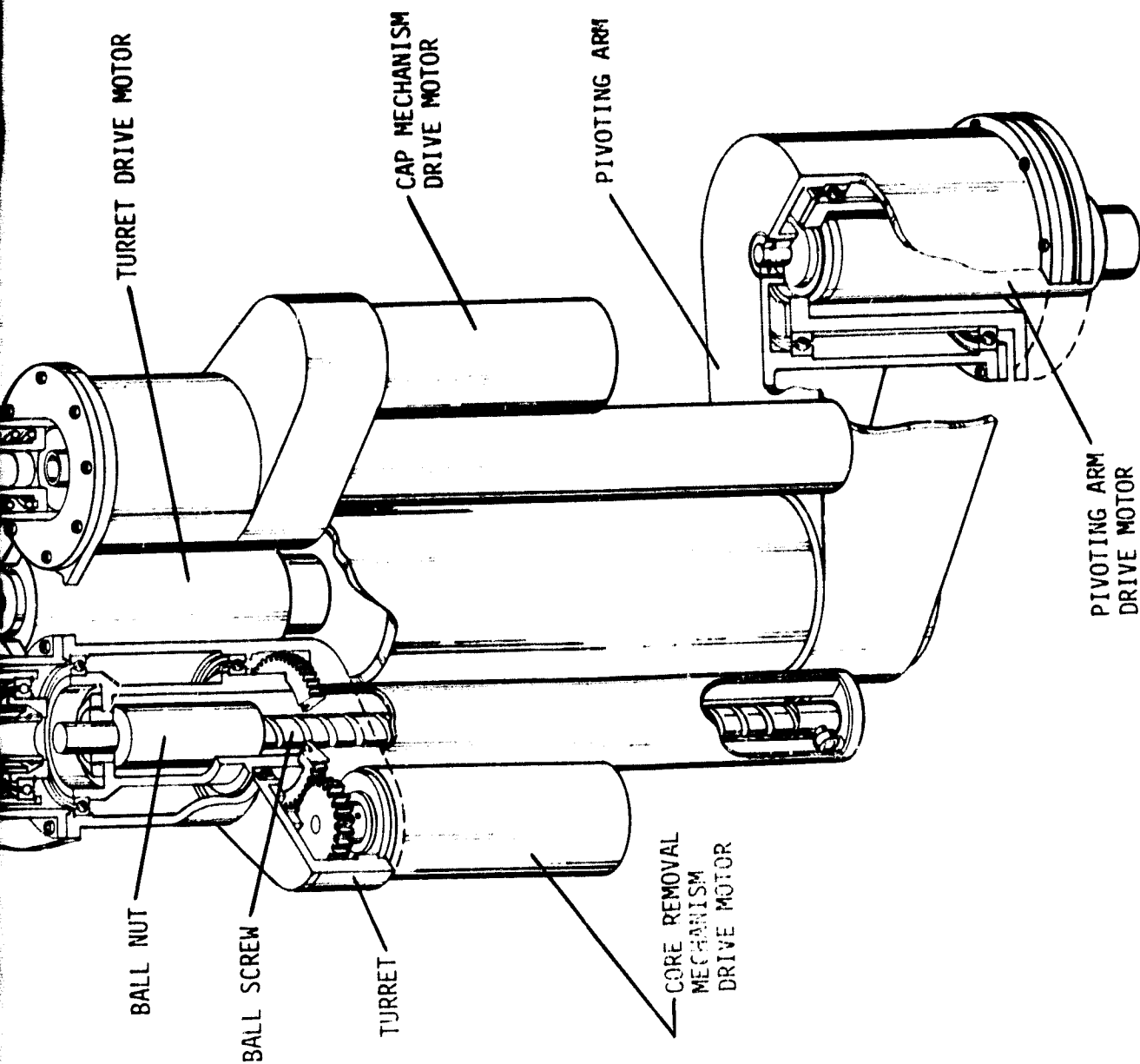


FIGURE 3-7 ROCK CORE HANDLING SYSTEM (REF MSR-120000)



2 FOLDOUT FRAME

The drill handling and core removal mechanism, core storage mechanism, and capping mechanism are mounted on a turret driven by a high torque, low speed gearmotor. A potentiometer is provided to determine angular position. The turret is positioned by the pivoting arm for alignment with the power head or sample container. By combining the turret and pivoting arm rotation, the large surface area of coverage required for depositing rock cores in the 5 x 5 sample container array is provided.

The turret has four positions; one position is utilized for the capping mechanism, two (2) positions contain a drill holder and core removal mechanism, and the fourth position is an empty drill holder mechanism only. This arrangement provides for a spare drill and a spare core removal mechanism in case one mechanism becomes jammed.

The core removal mechanism and capping drive mechanism are identical designs. The ball screw device provides a high linear force to push the rock core out of the drill or to force the container caps thru the cap holder. The ball screw is fixed to prevent rotation while the ball nut rotates. The nut is rotated by a gear and pinion driven by the low speed, high torque gearmotor. This, of course, is reversible so in the case of core removal, several cores can be acquired with the same drill bit.

3.6.6 Rock Core Sample Container and Release Mechanism (Dwg MSR-120100 - Figure 3-8)

This drawing (Ref Appendix D) illustrates the following:

- 1) Sample Container
- 2) Sample Retainer Membrane
- 3) Sample Container Caps
- 4) Container Release Mechanism

The sample container is a 6 x 6 x 11 centimeter magnesium box with 25 core sample holes. Section A-A illustrates the internal serrations at the opening of each hole. These serrations match the serrations shown in the Teflon cap which provide locking and sealing when the cap is forced into the hole.

A Teflon membrane is located behind the cap through which the core will be forced. The purpose of this membrane is to prevent the core from falling out after the core removal mechanism has been retracted. This is particularly important when this operation is performed with the drill perpendicular to the ground. The view labeled "Rock Core Sample Container" illustrates the container with a core sample in place. The capping mechanism has forced a cap into the container. When the capping mechanism moves, the holder is forced up to the container before the cap can move into the container. Upon retraction, the cap holder springs back leaving room for the turret to operate clear of the container. The single spring-loaded cap holder contains caps required for capping all 25 holes in the sample container.

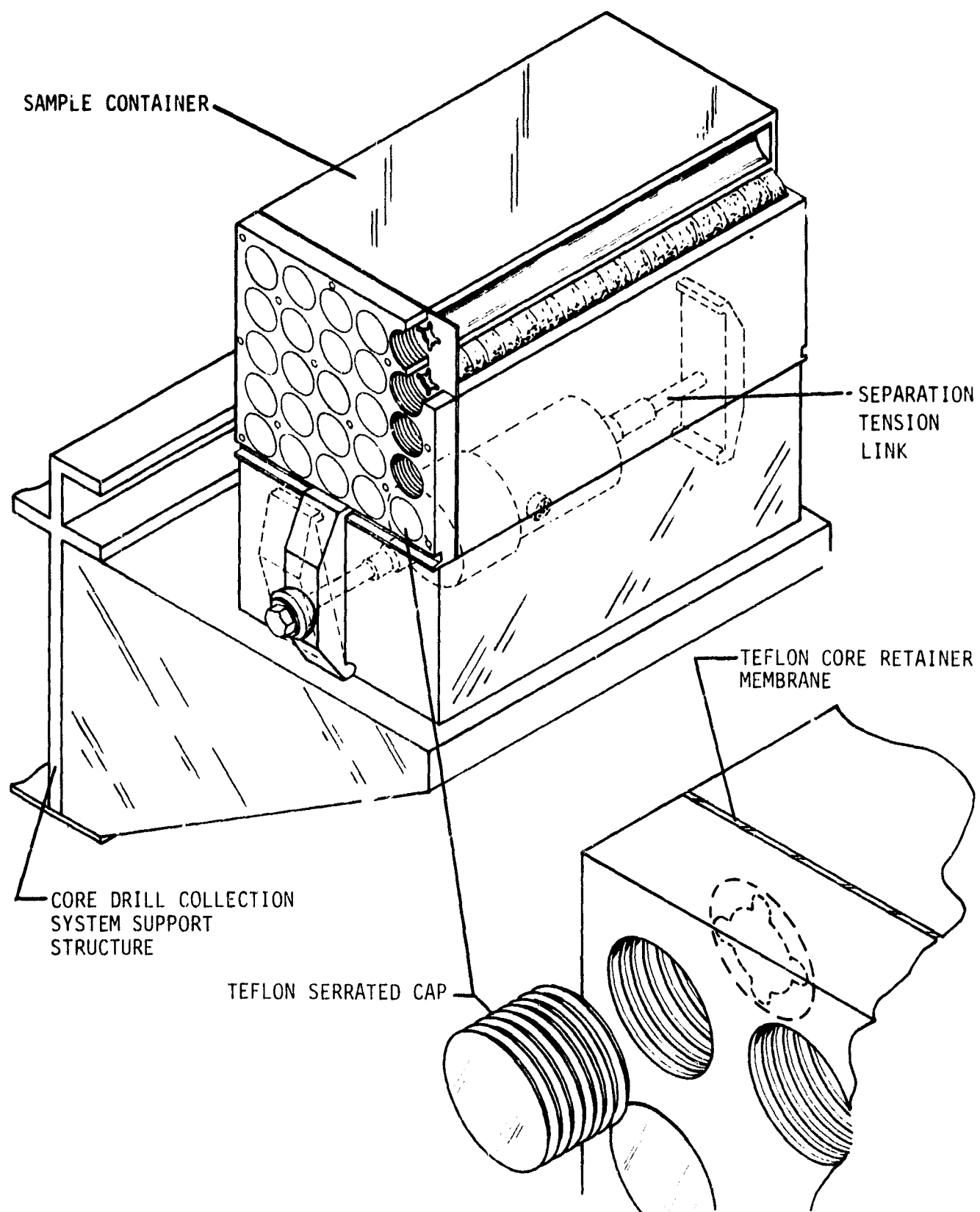


FIGURE 3-8 ROCK CORE SAMPLE CONTAINER AND RELEASE MECHANISM (REF MSR-120100)

When all samples have been obtained, the container must be released for transfer to the earth return vehicle by the remote manipulator. Release is accomplished by activation of a redundant tension link device. This releases the clamping force on the two spring loaded toe clamps, thus releasing the container for transfer.

3.6.7 Rock Core Drill Exchange Mechanism (Dwg MSR-120200 - Figure 3-9)

This drawing (Reference Appendix D) illustrates the following:

- 1) Power Head Collet Mechanism
- 2) Drill Holder

The purpose of this mechanism is to allow for transfer of drills from the power head to the (RCHS). This drawing illustrates a sequence of events starting with Sketch No. 1. The drill is in the power head. It is retained by a collet type retention device. The drill holder remains stationary while the power head is driven to move the drill into the holder. The tip of the drill makes contact with the holder and the holder makes contact with the collet sleeve (Sketch No. 2). As the power head moves in, the internal holder housing spring compresses and the collet sleeve is forced back compressing its spring as illustrated in Sketch No. 4. The collet fingers have now sprung away from the drill collar which clamped the drill in the collet. Note the retainer pin on the drill and section A-A. When the power head rotates 90°, the retainer pin is positioned for retention in the ring as shown in Section A.A. This rotation occurs in Sketch No. 4. The power head is retracted in Sketch No. 5. The retainer pin is locked in the detent, and the internal drill holder housing and collet sleeve return to their original positions. The power head is removed from the splined drill end as shown in Sketch No. 6 and the system is ready for its next operation.

A typical operating procedure for the (RCHS) MSR-120000 starting with the power head (less drill) in the retracted position is as follows:

- 1) Position drill holder on power head center line
- 2) Power head receives drill from drill holder
- 3) RCHS pivoted free of power head travel envelope
- 4) Rock core sample taken and power head moved above RCHS
- 5) Core drill installed into drill holder with core removal mechanism, and power head retracted
- 6) Turret positions drill holder with sample in line with predetermined sample container hole
- 7) Core removal mechanism activated forcing the core into the container

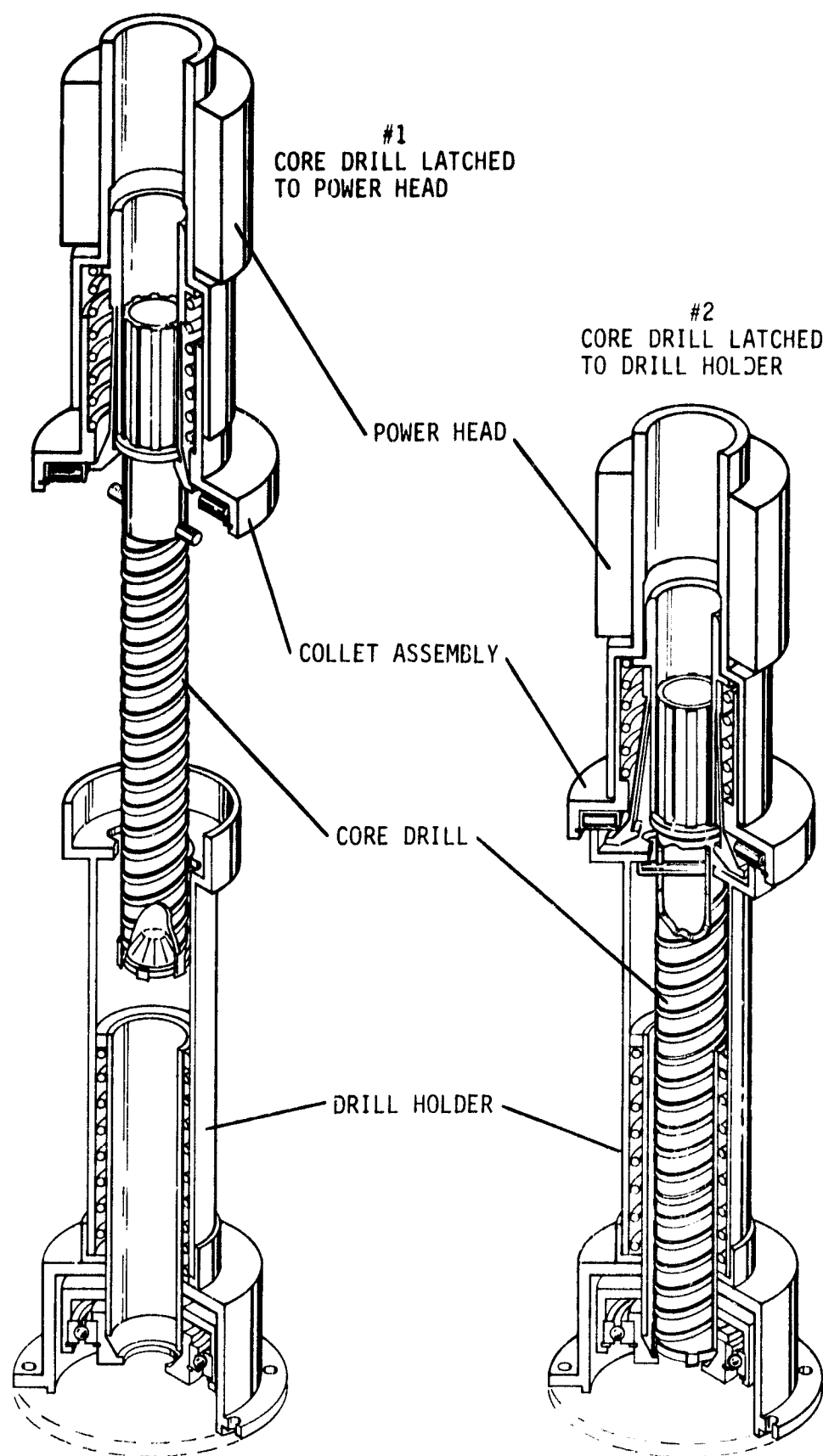


FIGURE 3-9 ROCK CORE DRILL MECHANISM (REF MSR-120200)

- 8) Turret rotated to position capping mechanism in line with sample container hole containing the core
- 9) Capping mechanism activated to cap hole
- 10) Turret rotated to position drill holder in line with power head
- 11) Power head picks up drill and proceeds to obtain next sample

If the drill becomes damaged, worn or jammed with a sample, the spare drill is available for continued operation.

3.6.8 Regolith Sample Handling System (RSHS) (Dwg MSR-130000 - Figure 3-10)

This drawing (Ref Appendix D) illustrates the following:

- 1) Turret Assembly
- 2) Translation Arm
- 3) Sample Container
- 4) Cap Containers
- 5) Packaging and Capping Mechanism
- 6) Sample Container Release Mechanism

The RSHS is designed to accomplish all tasks necessary for the collection and packaging of regolith core samples.

These tasks include:

- 1) Providing the full complement of sample containers necessary to satisfy the mission requirements
- 2) Providing a means for capping the sample containers
- 3) Providing a means for positioning the sample containers in line with the core drill for sample transfer.

This system is made up of the turret, the pivoting arm and the pack and cap mechanism. The turret which houses the regolith sample containers is rotated by a low speed, high torque gearmotor which positions the container for filling, packing or capping. The pivoting arm will position the sample container in line with the drill for filling purposes and then rotate the mechanism clear of the power head travel envelope during drilling operations. This motion is also powered by a low speed, high torque gearmotor. Each drive receives angular position information from a potentiometer.

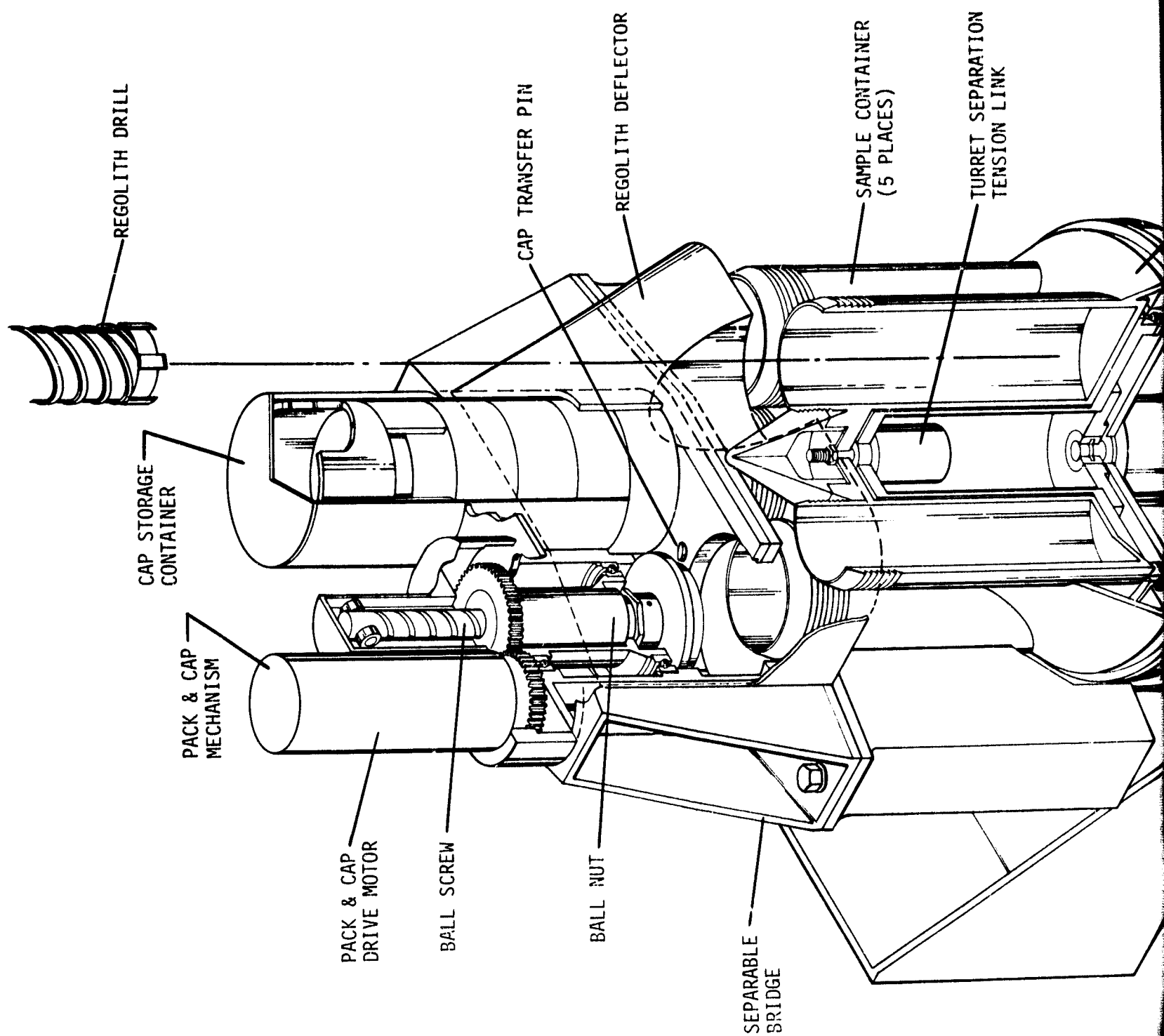
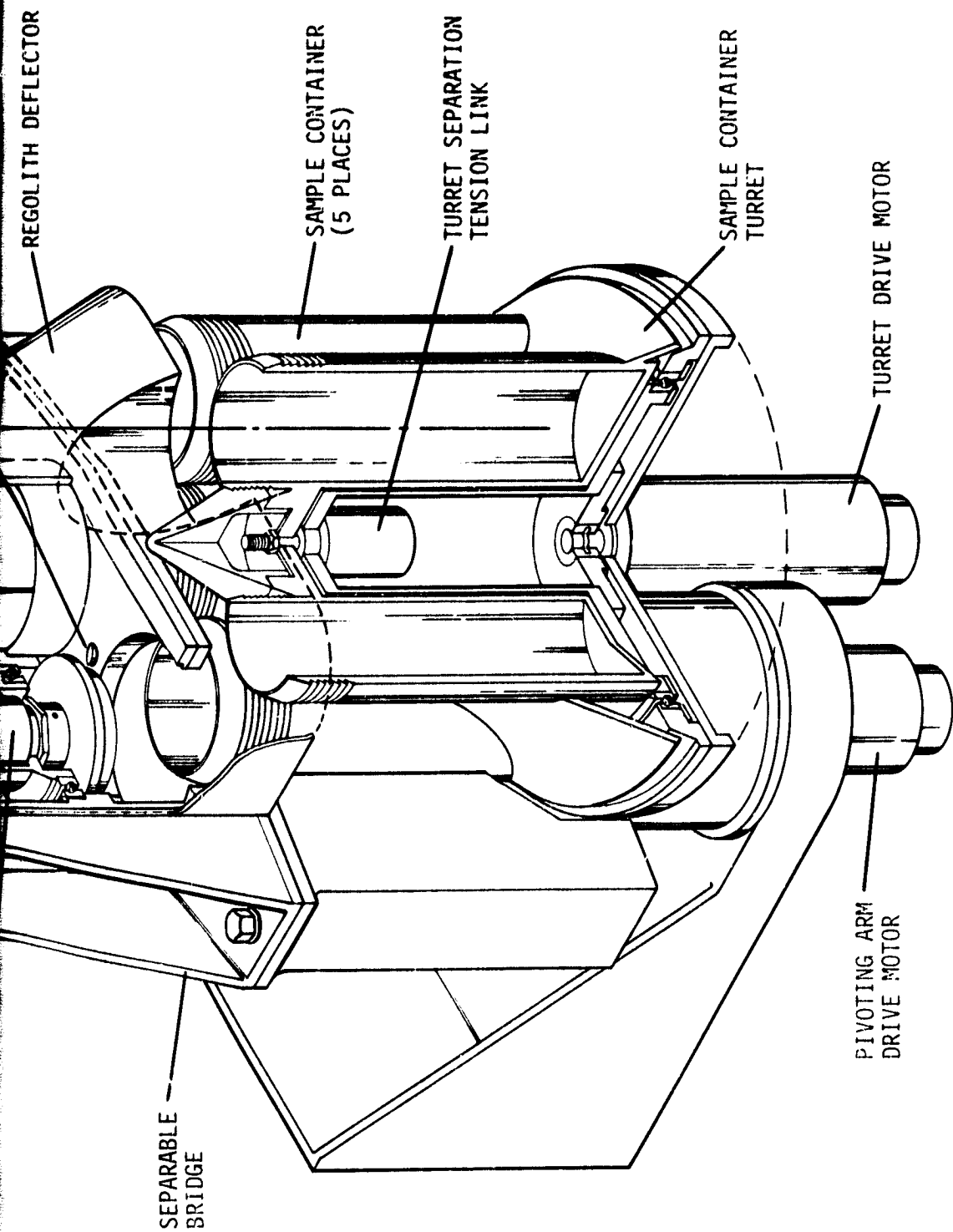


FIGURE 3-10 REGOLITH SAMPLE HANDLING SYSTEM (REF MSR-130000)



2 FOLLOW-UP FRAME

The pack and cap mechanism is mounted on a bridge located above the turret. The mechanism is separated upon completion of the mission to allow removal of the turret containing the full sample containers for transfer to the return vehicle. Turret separation occurs upon activation of the tension link release device.

The pack and cap mechanism is identical to the rock core removal and capping devices shown for the (RCHS) except the travel is much shorter. The linear drive provides a high linear force for packing measured, 10-cc increments of regolith in the container and for installing of container caps.

The cap storage container shown in section D-D contains 5 caps. It is a negator spring loaded cartridge. The turret is rotated counter clockwise to move a cap from the storage container to a position in line with the sample container. The cap transfer pin is tapered in a direction which allows it to engage the cap only when the turret is rotated counter clockwise. This moves the cap into capping position. The linear drive then presses the cap onto the regolith container. As each cap is removed from the cap container the next cap is forced down into transfer position.

A typical operating procedure (Ref MSR-130100 Regolith Sample Collection Tube Procedure) illustrated in Figure 3-11, for the (RSHS) is as follows:

- 1) An empty sample container is positioned by the turret in the sample receive position
- 2) The one meter drill is attached to the power head. (See MSR-110000 for drill attachment procedure)
- 3) Power head drills 10-centimeter deep hole for first 10-centimeter core sample
- 4) Power head moves up to clear RSHS
- 5) RSHS pivoted into line with drill
- 6) Drill operated to shake sample into 10-cc pre-measured volume of sample tube. Excess spills over side
- 7) RSHS rotates sample tube under packing mechanism and compacts sample
- 8) Packing mechanism retracts, RSHS rotates to clear power head travel envelope
- 9) Power head drills a new hole, 20 centimeters deep, and deposits the sample into pre-measured volume of sample tubes as before. The "last-in, first-out" scheme ensures that the acquired sample deposited in the tube came from a 20-centimeter depth.

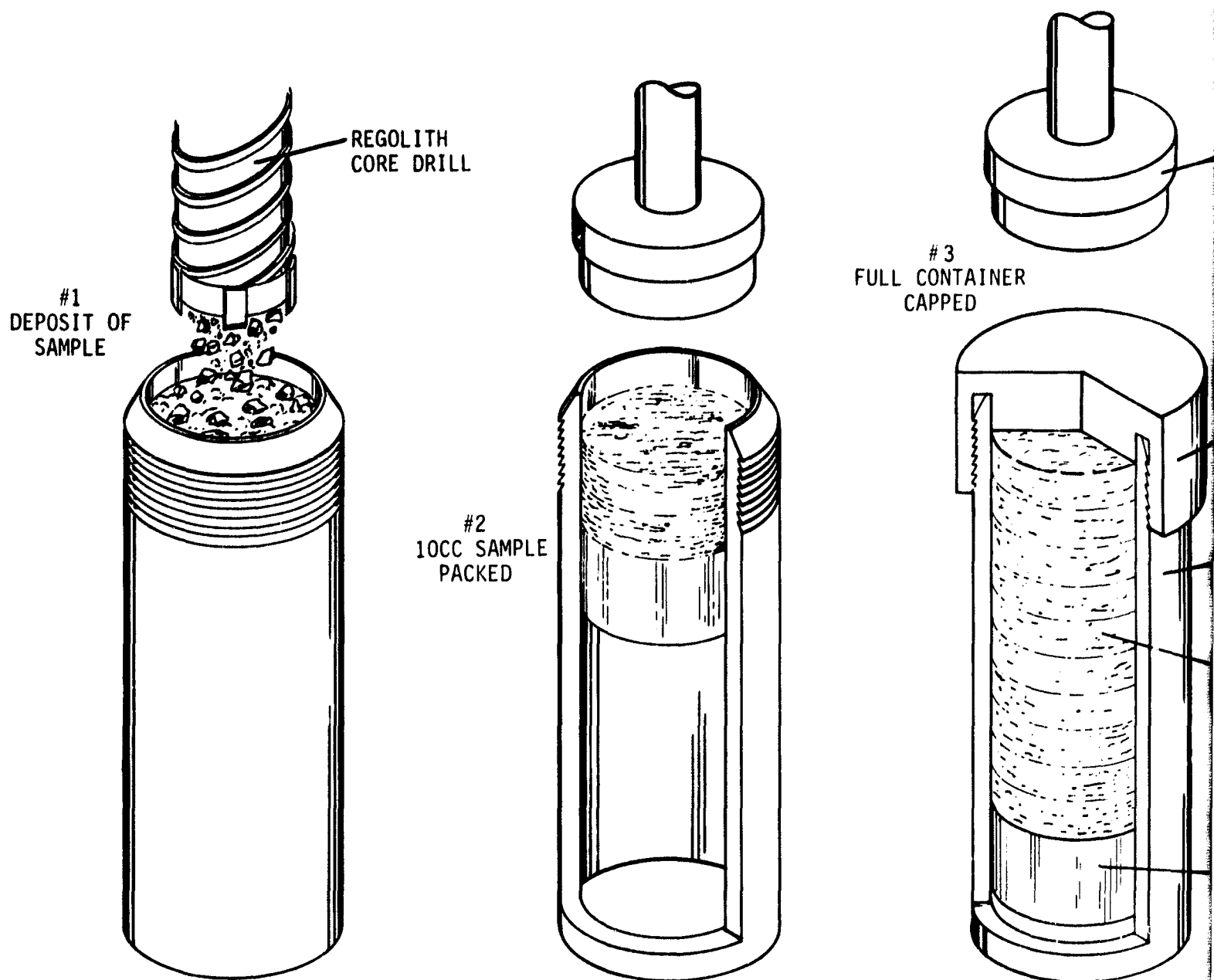
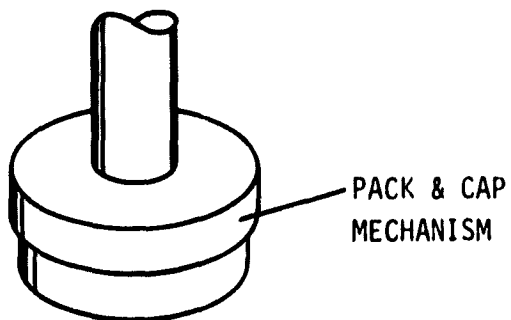
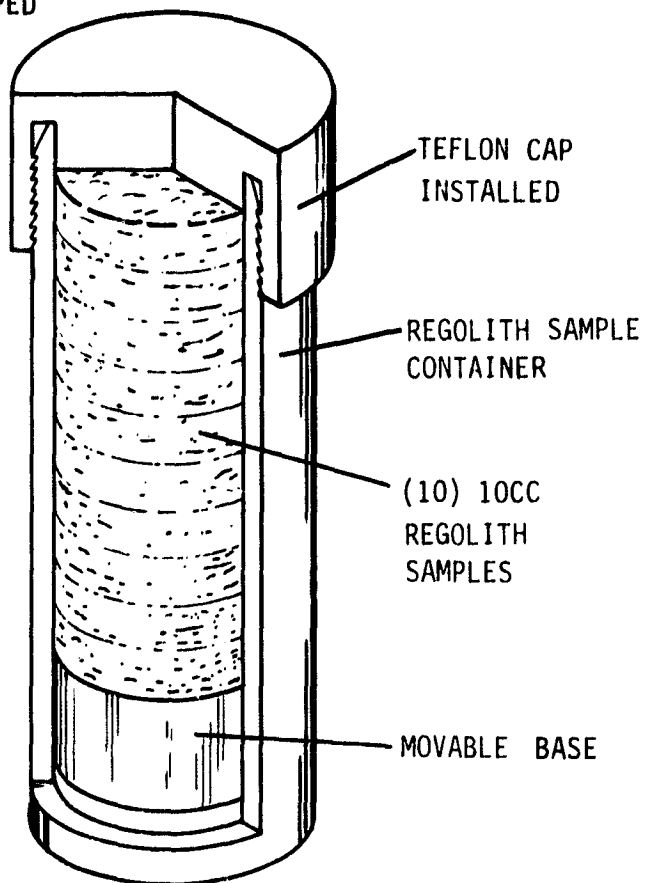


FIGURE 3-11 REGOLITH SAMPLE COLLECTION TUBE PROCEDURE (REF MSR-130100)



#3
FULL CONTAINER
CAPPED



FOLDOUT FRAME

- 10) Repeat these operations in 10-centimeter steps until sample tube is full which will occur during drilling of the final (1-meter) hole.
- 11) Rotate turret counter clockwise to position cap under capping mechanism
- 12) Press cap on sample tube

This procedure may be repeated to fill the remaining sample tubes each with ten, 10-cc samples.

The cap and sample tube have matching serrations to seal and lock the cap in place.

3.7 Drill Performance vs Mass and Power Tradeoffs

3.7.1 Mass

The mass of the Rover-mounted drill, which includes the capability of acquiring twenty-five 1-cm diameter x 10-cm long rock cores, and five regolith sample collection tubes each capable of ten, 10-cc samples, is tabulated in Table 3-7.

Table 3-7 Rover-Mounted Drill Subsystem Mass

Drawing	Title	Mass (Kg)
MSR-110000	Core Drill Collection System (CDCS)	18.7
MSR-110100	Regolith and Rock Core Drills (3) 10-cm Rock Drills -0.4 Kg (1) 1-meter Regolith Drill -0.5 Kg	0.9
MSR-100100	Core Drill Positioning System (CDPS)	3.6
MSR-120000	Rock Core Handling System (RCHS)	5.9
MSR-120100	Rock Core Sample Container and Release Mechanism	0.7
MSR-130000	Regolith Sample Handling System	5.4
N/A	Electronic Control Sequencing Unit	6.0
	TOTAL	41.2

There may be some conservatism in the mass estimates; however, some conservatism is mandatory due to the relatively low design maturity of the system. A follow-on program consisting of a detailed design of the drill, and preferably, fabrication of an operational prototype unit is necessary before a more accurate mass estimate can be made.

It is possible to qualitatively make some judgements which, if implemented, could reduce the system mass. A tabulation of potential performance decrease and associated mass reduction is presented in Table 3-8.

Table 3-8 Drill Mass vs Performance

Performance Reduction	System Mass (Kg)
1. Eliminate Regolith Coring Capability From Rover - Reduces Vertical Traverse, - 3 Kg - Eliminates MSR-110100 Regolith Drill, -0.4 Kg - Eliminates MSR-130000, -5.4 Kg - Reduces Complexity of Control Unit, -0.5 Kg	31.9
2. Delete "Autonomous Characteristic" and Permit JPL Robotic Arm to Remove Rock Cores from Drill Bits and Package Separately - Same as Item No. 1, -9.3 Kg - Eliminates MSR-120000, -5.9 Kg - Reduces Complexity of Control Unit, -0.5 Kg	25.5
3. Mount Drill to Front Side of Rover and Eliminate Core Drill Positioning System - Same as Item No. 2, -15.7 Kg - Eliminates MSR-100100, -3.6 Kg	21.9

3.7.2 Power

The total power required for drilling operations is primarily dependent upon the type of material being drilled, and the number of samples being acquired. Additional quiescent power is used by the electronic control sequencing unit and the various auxiliary drill drive subsystems, but this is relatively small compared to that consumed by the power head. Table 3-9 provides a tabulation of partial drilling power requirements (drilling only) and the approximate required battery recharge time from a 25-watt RTG. A more comprehensive description of a potential Rover power system is described in a subsequent section of this report.

Table 3-9 Drill Power Requirements vs Cored Material⁽¹⁾

Cored Material	Power Req't (Watt-Min)	Battery Recharge Time From 25-Watt RTG (min)
1-cm dia x 10-cm 5% Porosity	472	19
1-cm dia x 10-cm 40% Porosity	148	6
1.9-cm dia x 50-cm Dry Regolith	236	9
1.9-cm dia x 1-meter Dry Regolith	472	19

(1) Data calculated from Table 3-3 Data, System No. 3 and includes only the coring energy requirement.

4.0 SIMULATED PERMAFROST DRILLING TESTS

4.1 Study Task Objectives

It is anticipated that the Mars sample return mission will involve primarily core drilling and surface sampling in materials (regolith and rocks) with physical properties similar to those encountered during the lunar missions (U.S. and Russian) and during the Mars Viking Landers 1 and 2 operations. However, some investigators are also interested in Earth-return core samples acquired from the Mars polar regions where subsurface permafrost may be encountered. The objectives of this study task were to:

- 1) Procure an astronaut training unit lunar drill from the U.S. Air and Space Museum in Washington, D.C.
- 2) Fabricate an economical simulated permafrost drilling model
- 3) Conduct cursory tests using the lunar drill (a rotary-percussion system employing tungsten carbide core bits) to identify problem areas
- 4) Obtain data from terrestrial arctic and antartic drilling projects and assess for potential applicability to the Mars missions
- 5) Make recommendations for additional permafrost coring studies

4.2 Astronaut Training Unit Lunar Drill Procurement

An astronaut training unit Apollo Lunar Surface Drill (ALSD), Martin Marietta Part Number 467A8060000-059, Serial Number 3, was returned to NASA/JSC from the Smithsonian National Air and Space Museum in Washington, D.C. The unit was loaned GFE to Martin Marietta for the purpose of performing the simulated permafrost drilling tests. A checkout of the ALSD revealed that it was functioning properly even though it had not been operated for approximately six (6) years.

4.3 Simulated Mars Permafrost Models

Two (2) models were prepared in support of the simulated permafrost coring tests. These models were believed to represent "boundary extremes" of potential Mars permafrost drilling conditions. Additionally, the economics of this study task dictated that the tests be conducted under laboratory conditions at a pressure of one (1) atmosphere, i.e., no thermal-vacuum environment. The test models were fabricated as follows:

Model No. 1 (Water Saturated Regolith)

- 1) Material: Lunar nominal regolith simulant previously used for the Mars-Viking project; material consists of crushed basalt graded from a micron to millimeter size fraction, similar to that described by Figure 4-1.

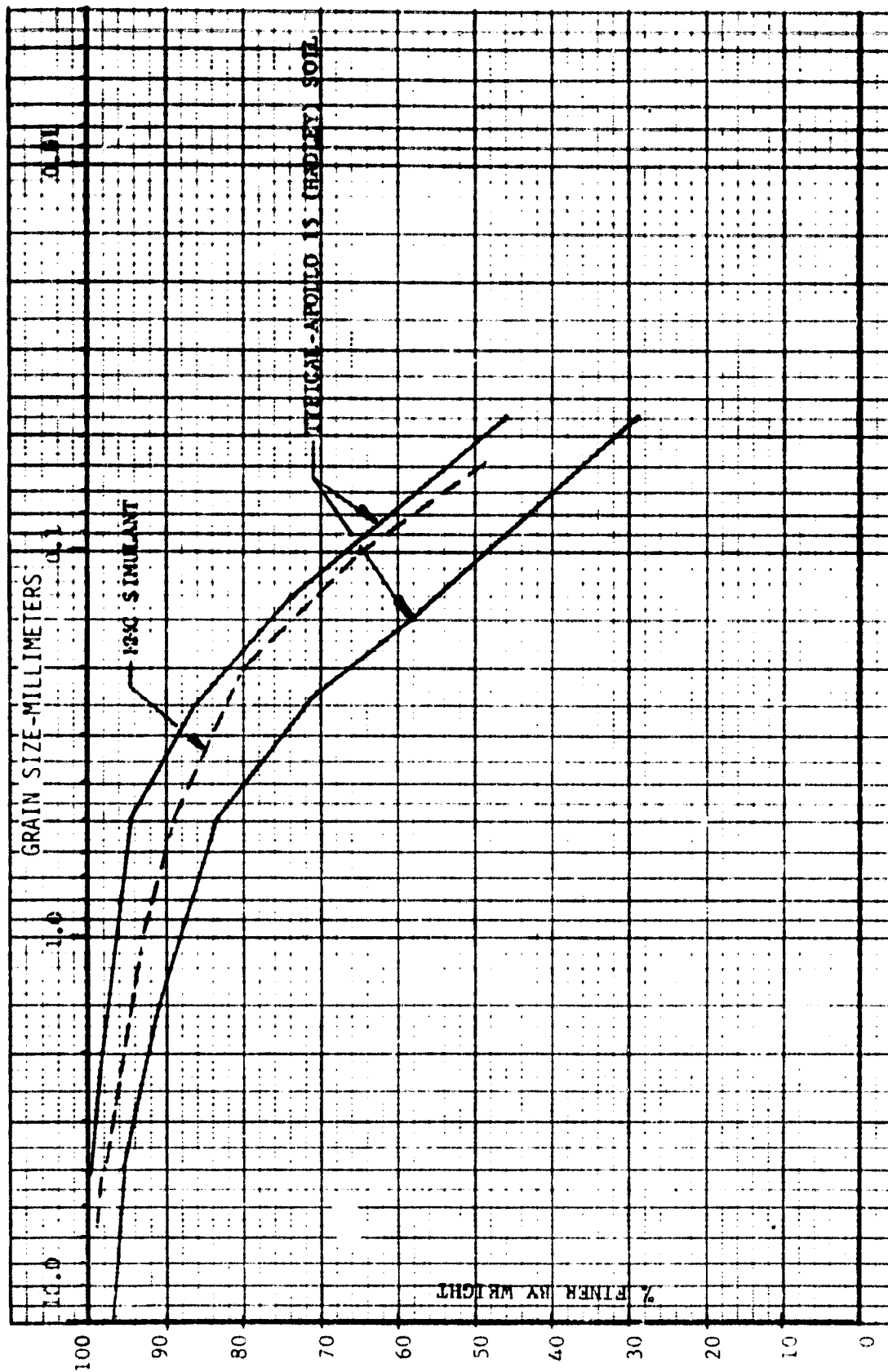


Figure 4-1 Lunar Nominal Regolith Simulant Particle Size Description

- 2) Container: 0.5 meter diameter x 0.9 meter deep
- 3) Preparation: Material placed in container in layers of approximately 10 centimeters each with the dry bulk density controlled to 1.6 gr/cc (100 lb/ft³) - Water added to each layer until saturation as evidenced by excess free water forming at the top of each layer.
- 4) Temperature: The container (with LN₂ Cooling tube) was placed in a styrofoam enclosure - Regulated LN₂ was circulated through the cooling coil and box enclosure until the model was stabilized for 24-hours at -52 to -56°C (-62 to -69°F).

Model No. 2 (Water Ice)

- 1) Model consisted of a 0.3 meter deep ice block frozen to -37°C (-35°F).

Figure 4-2 is a photograph of Model No. 1 prior to cool-down.

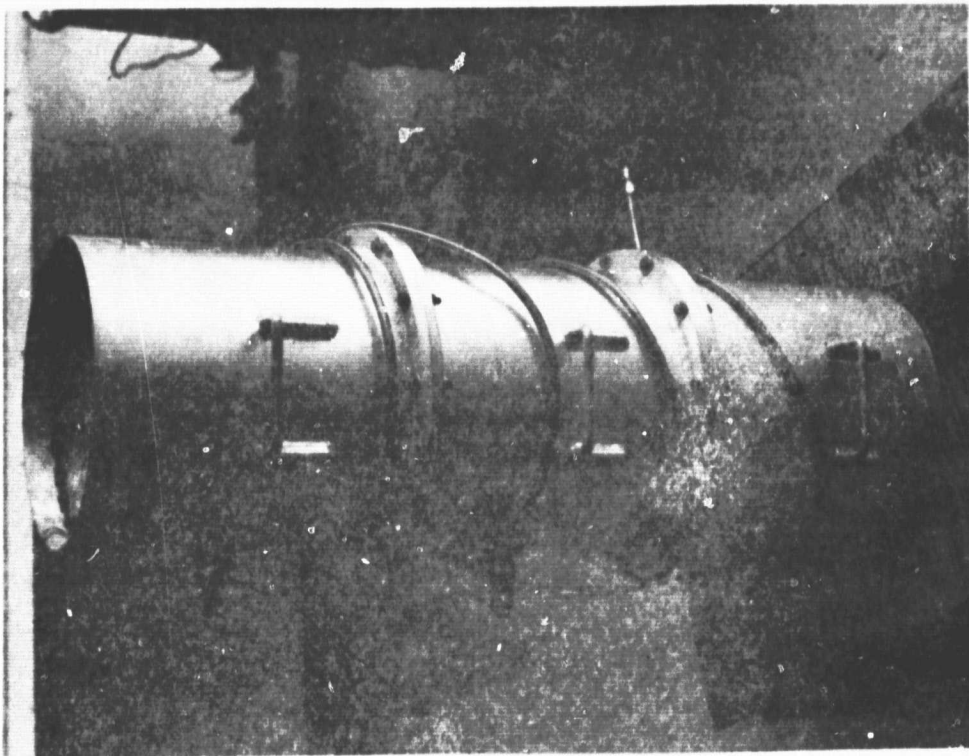
4.4 Simulated Permafrost Coring Tests

Figure 4-3 is a photograph of the simulated Mars permafrost coring tests. For each test the ALSD power head was manually operated outside of the styrofoam enclosure with only the core bit and stem penetrating the frozen material. The core bit and stem were pre-cooled to the model environment prior to commencing each test.

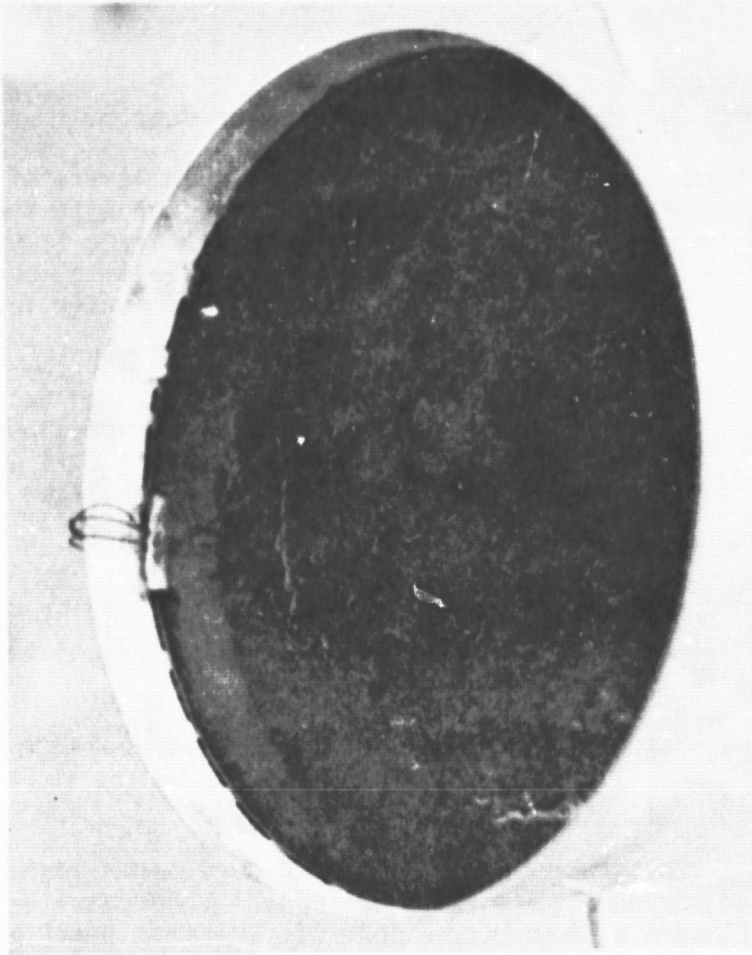
A summary of the test results includes the following:

Model No. 1 (Water Saturated Regolith)

- 1) Maximum depth attained was approximately 15 centimeters
- 2) Penetration rates extremely slow (2-5 cm/min)
- 3) Excessive drilling torques encountered--greater than 277 cm/Kg (20 ft-lbs)
- 4) Examination of core bits indicated that:
 - a) Material melts and refreezes in core bit flutes thus precluding cuttings transport up helical flutes as shown in Figure 4-4.
 - b) Core stem freezes rapidly to bottom of hole immediately after termination of each drilling operation regardless of drilling time, i.e., 5 seconds or 5 minutes.



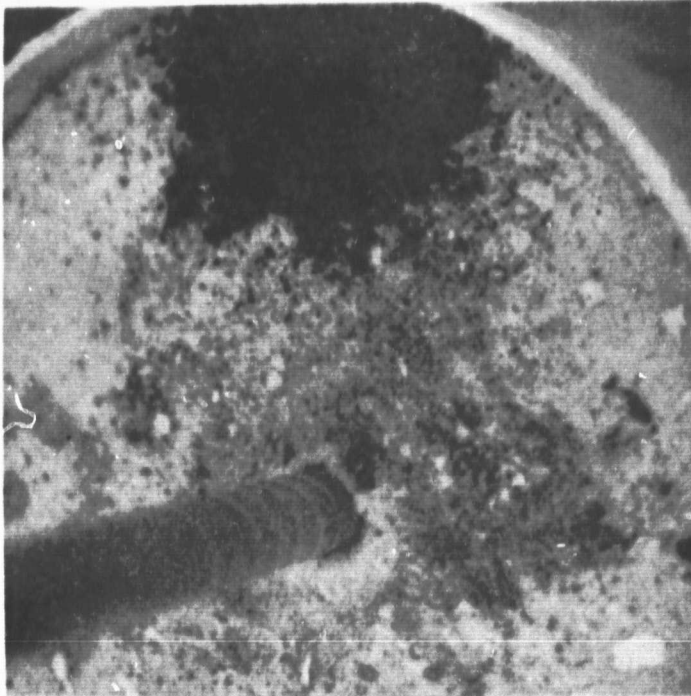
(a) Container



(b) Water-Saturated Simulant

Figure 4-2 Water-Saturated Mars Surface Simulant

ORIGINAL PAGE IS
OF POOR QUALITY



(b) Frozen Subsurface Cuttings
Transported to Surface

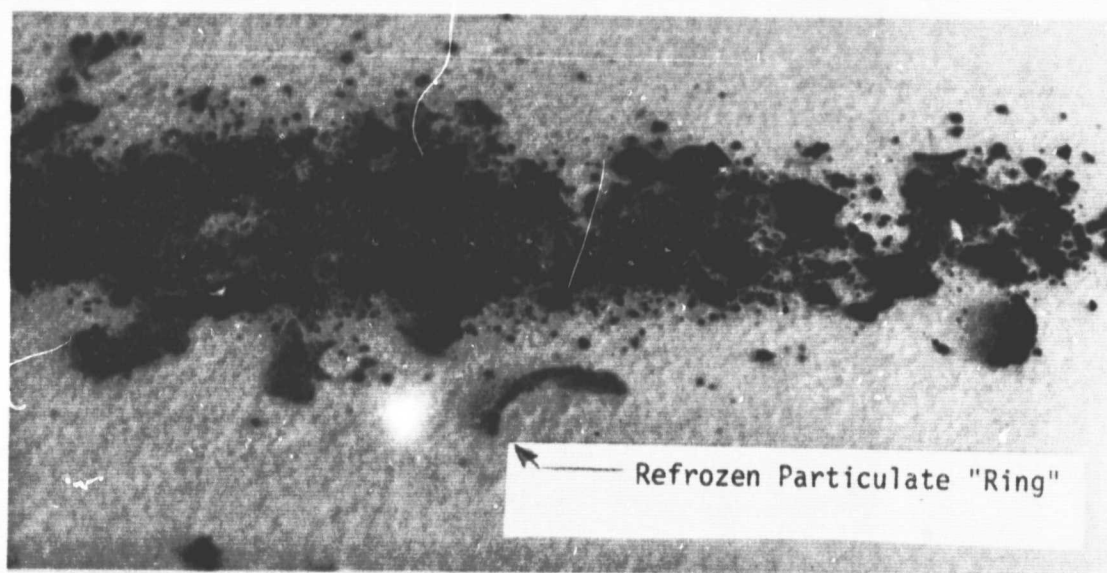


(a) Apollo Lunar Surface Drill (ALSD) Operation

Figure 4-3 Simulated Mars Permafrost Drilling



(a) Cores and Jammed Flutes



(b) Cuttings and Refrozen Particulate "Ring"

Figure 4-4 Typical Core Specimens

Model No. 2 (Water Ice)

- 1) Drilling rates of 80 cm/min attained with no excessive torque or freezing of bit to bottom of hole.
- 2) Core of "crushed ice" filled core stem, i.e., good core recovery.

It is interesting to note that penetration rates of 50 to 80 cm/min are easily attainable in dry regolith simulant. Drilling rates of 80 cm/min in pure ice were demonstrated during this test. However, the ice/regolith combination drills with the hardness of dense basalt, and the resultant generation of heat due to the slow penetration rates apparently results in a melting and refreezing action on the cuttings. This jams the helical cuttings transport flutes and causes excessive rotary drilling torques.

4.5 Commercial Earth Drilling Techniques Used for Ice and Frozen Soil

A brief survey was conducted to investigate the drilling techniques commercially used in the Arctic and Antarctic on earth. Dr. L. D. McGinnis of Northern Illinois University, Dr. D. Anderson of the University of New York, and Mr. A. R. Tice of the U.S. Army Cold Regions Research and Engineering Laboratory (CRREL) were particularly helpful. Representative drilling technique data are published in Ref 1-9 and 26, 27 of this report. A summary of the drilling techniques often used in the Arctic and Antarctic regions are tabulated in Table 4-1.

Table 4-1 Commercial Earth Drilling Techniques
Used for Ice and Frozen Soil

Drilling Location	Drilled Material	Drill Technique	Drilling Fluids
Dry Valley Drilling Project McMurdo Sound, Antarctica	Ice/Soil/Rocks	Rotary Diamond	1) Diesel Fuel/ Methanol/Geltowe 2) CaCl_2 /Clay/Water 3) Salt Brine
Barrow, Alaska	Ice/Sand/Silt/ Gravel	Tungsten Carbide Drag	Refrigerated Compressed Air
Greenland Ice Sheet	Ice	1) Thermal Drill 2) Rotary	Glycol
Antartic Ice Sheet	Ice	1) Thermal Drill 2) Rotary Drill	Glycol
Fairbanks, Alaska	Ice/Soil	1) Vibratory 2) Rotary/ Percussion	Compressed Air

NOTE: The main objective of all permafrost drilling schemes is to main "below freezing" drilling temperatures.

4.6 Recommendations for Future Mars Permafrost Tests

The results of these preliminary simulated Mars permafrost tests were less than successful. It is believed that a substantial effort will be required to determine the optimum techniques and equipment needed to successfully core permafrost materials within the constraints of a Mars sample return mission. A preliminary list of recommendations includes the following:

- 1) Perform additional drilling tests in simulated permafrost models at Mars pressure, i.e., 5-10 millibar pressures may reduce thawing/freezing problem via liquid sublimation.
- 2) Reassess validity of water-saturated permafrost models and re-test less severe models.
- 3) Engage the services of CRREL and/or other consultants who are knowledgeable in the physical properties of ice/soil materials and have experienced the problems associated with drilling in the polar regions.
- 4) Initiate extensive study/development program to adapt promising commercial permafrost drilling techniques to the Mars application including the potential use of compressed gas.

5.0 ROCK BREAKER SYSTEM

5.1 Study Task Objectives

It is anticipated that a rock breaker device, as distinct from a crusher, will be required to produce smaller rock samples from rocks too small to core. The Rover-mounted drill described in Section 3.0 was designed with a positioning system which can translate to the surface and restrain rocks as small as approximately 15 cm (6 in.) for coring operations. Therefore, the rock breaker must be capable of accommodating rocks in the 10-15 centimeter size range such that smaller samples more appropriate for return to earth can be produced.

Examination of the sampling equipment location options (Ref Paragraph 2.3) resulted in the recommendation that the rock breaker system be located on the descent vehicle (lander). Other specific objectives of the study included the following:

- 1) Generate top-level design configuration drawings of the rock breaker which will reduce specimens to ≤ 2 centimeters in diameter.
- 2) Include a technique for estimating reduced sample mass
- 3) Provide a technique for purging the device in preparation for a new sample.

5.2 Rock Breaker Design (Dwg MSR-200000)

This drawing (Ref Appendix D) illustrates the following:

- 1) Hammer and crush bin capable of accommodating rocks in the 10 to 15 cm (4 to 6 in.) size range.
- 2) Single motor operation to perform the four (4) functions of hammer retract, lock, release, and the deposition of a reduced sample to an inspection pan.
- 3) System delivery of ten (10) rock breaking blows per minute with a hammer force of approximately 3.5 kg (7.8 lb).

Note: This design approach assumes that the rock crusher is mounted on the main lander, and that a lander-mounted robotic arm (or rover-mounted robotic arm) is available for operational assistance to include sample loading and purge of samples to be discarded. Selection of samples to be returned to earth will be accomplished via lander or rover-mounted cameras.

In addition to the top level design drawing provided in Appendix D, Figure 5-1 schematically illustrates operation of the rock breaker. The operating profile of the system includes the following:

- 1) Sample Catch Pan Release
 - A) Energize non-explosive pin puller to allow spring-loaded sample catch pan to rotate to deployed position.
- 2) Hammer and Bin Cover Retract and Lock
 - A) Rotate drive wheel CCW permitting pin "A" to retract hammer pull bar to "cocked" position.
 - B) Rotate drive wheel slightly CW permitting Pin "B" to position hammer lock cam bar to "locked" position.
 - C) Place rock in sample crush bin using robotic arm
- 3) Hammer Crush Cycle
 - A) Rotate drive wheel CCW which lifts hammer slightly followed by lock cam disengagement.
 - B) Continued CCW drive wheel rotation causes hammer drive link to stop against bin dump link which allows pin "A" to rise out of pawl and release hammer (and bin cover) to crush rock.
 - C) Step (B) can be continued as long as necessary to ensure required level of rock crushing.
- 4) Crush Bin Sample Deposition Cycle
 - A) Perform Steps 2(A) and 2(B)
 - B) Rotate drive wheel CW until bin dump link engages Pin "A" and rotates bin to over-center position at which time the crush bin "gravity-assist" falls to fully inverted position depositing crushed rock on sample catch pan.
 - C) Continue to rotate drive wheel CW until opposite end of bin dump link slot engages Pin "A" and rotates bin cover to over-center position at which time the crush bin "gravity-falls" to original upright position.
- 5) Sample Inspection, Selection, Purge
 - A) Samples inspected via lander or rover cameras. Lander or rover-mounted robotic arm assist may be desired.

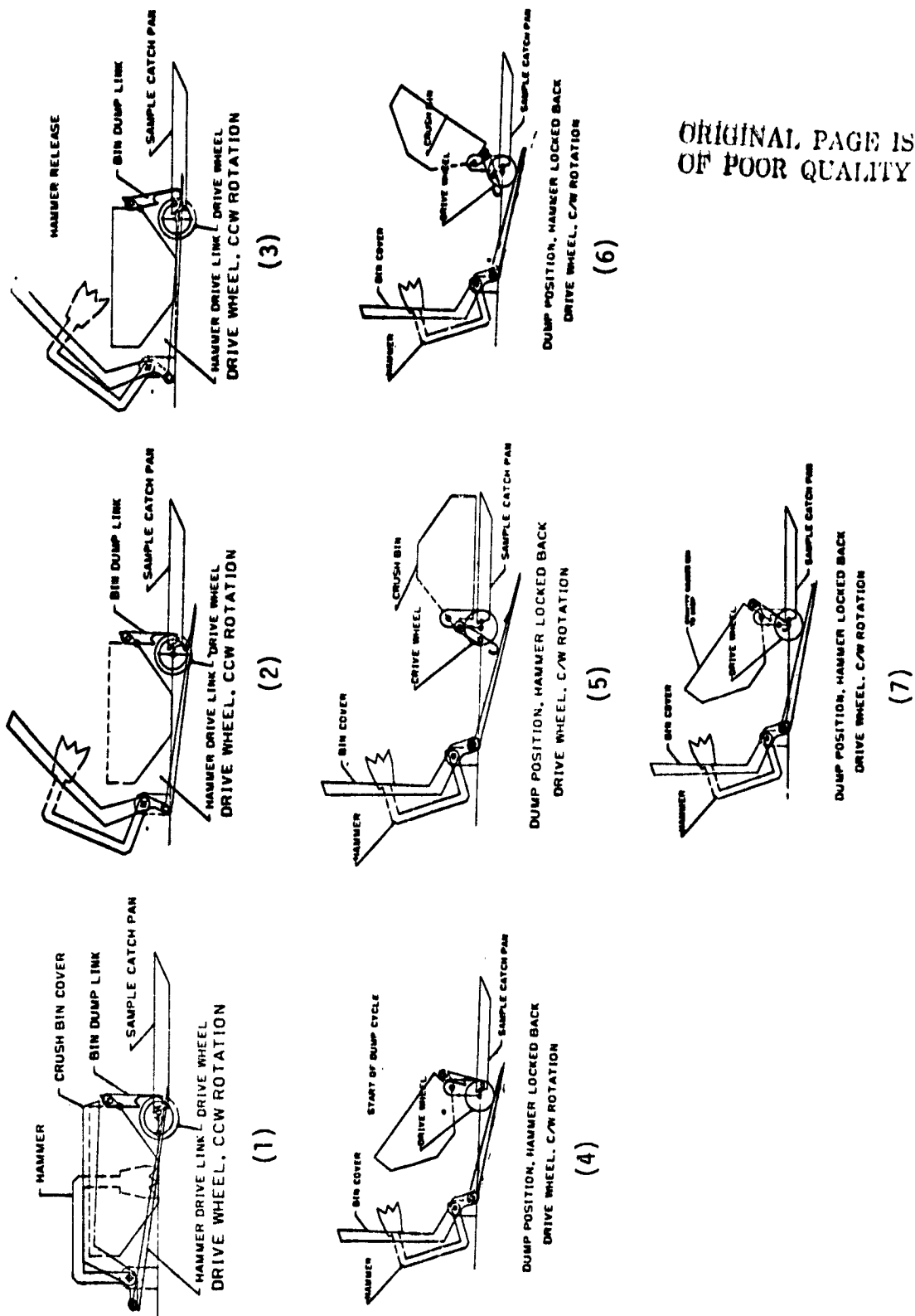


Figure 5-1 Rock Breaker Operating Sequence

- B) Samples to be returned to earth selected and packaged in earth return canister via robotic arm.
- C) Residual material purged by depressing spring-loaded sample catch pan downward with robotic arm.

5.3 Mass and Power

The estimated mass for the rock breaker is 2.3 kg (5 lbs) for the mechanical assembly and 1.4 kg (3 lbs) for the electronic control unit which totals to 3.7 kg (8 lbs) for the entire system. It is assumed that software and control logic will be included in the descent stage (lander) computer.

The peak operating power during the "hammer cycle" is approximately 20 watts, and 10 watts during the dump cycle.

Estimates of mass and power were based upon the design configuration, and upon experience with similar devices designed and fabricated for other programs. Figure 5-2 illustrates several rock breaker systems which were developed under Martin-Marietta Independent Research and Development (IRAD) tasks.

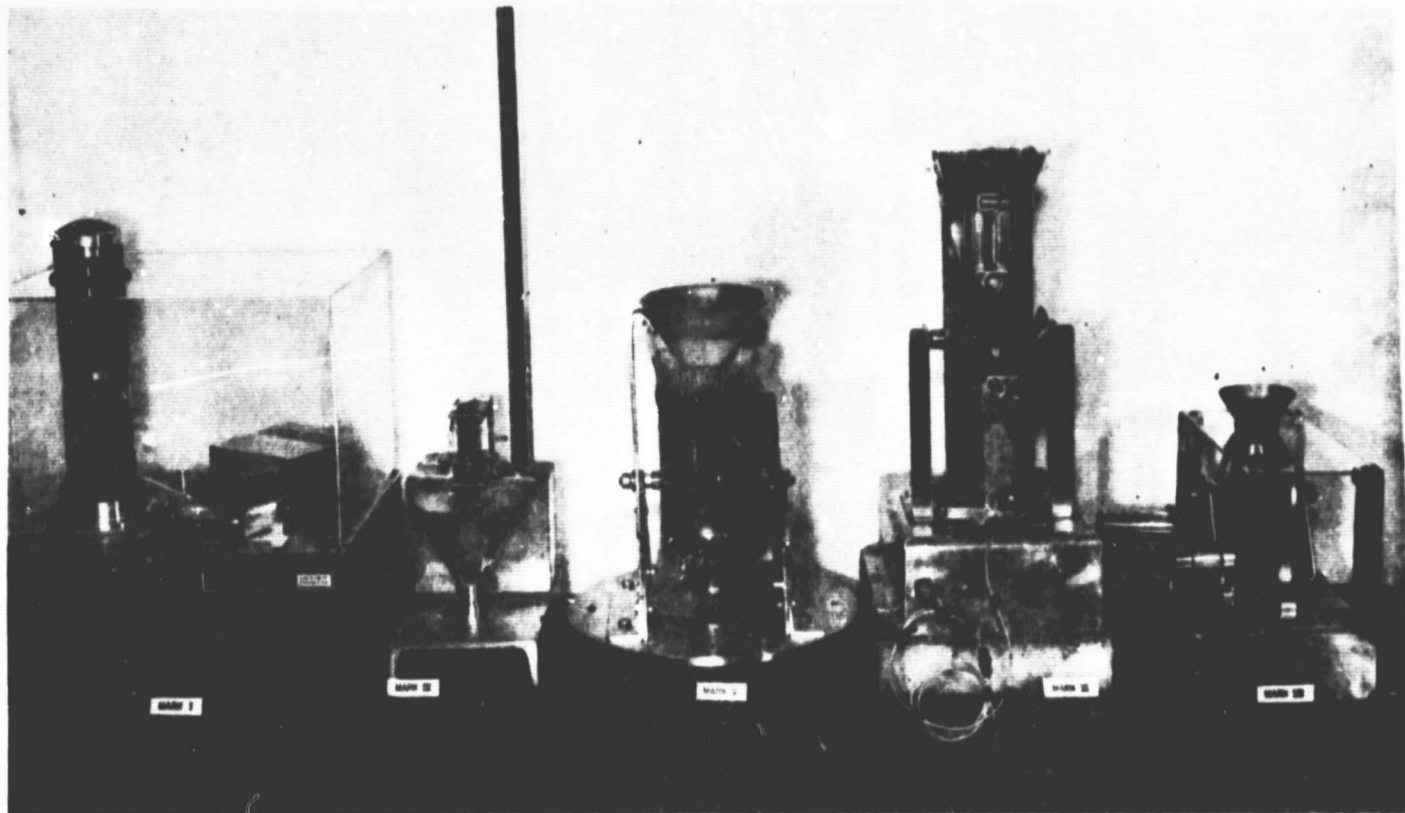


Figure 5-2 Rock Breaker Breadboard Systems

6.0 SAMPLE CONTAINMENT

6.1 Study Task Objectives

Sample containers will be required for the selected regolith cores, rock cores, and the small particulate and rock samples acquired from the surface and from the rock breaker. Additionally, container(s) will be required to transport all individual samples acquired on the surface of Mars to Earth. Specifically, consideration will be given to the following functions:

- 1) A technique and conceptual design for packaging the selected regolith cores or portions thereof in hermetically sealed, identified containers.
- 2) A technique and conceptual design for packaging the rock cores in identified containers.
- 3) A technique and conceptual design for automatic or semi-automatic packaging of the small rocks and surface particulate samples in identified containers.
- 4) A conceptual design for the Mars-to-Earth sample return container(s). Consideration should be given to optimum configuration for maximum storage capacity, maintaining all of the samples at the Mars ambient temperature or lower.

6.2 Design Approach

The design objectives (1) and (2) above were accomplished by the integrated design approach previously described for the Rover-mounted drill. Specifically, a tubular container design was generated which will accommodate selected samples at discrete depths from a 1-meter regolith core. Five (5) of these tubular containers are provided - each capable of accommodating ten, 10-cc samples, presumably acquired at 10-centimeter depth intervals over a 1-meter depth. A rock core container capable of accommodating twenty-five (25) cores was also designed. "Source traceability" for both the regolith and rock cores is inherent with the hardware design.

Design objectives (3) and (4) were addressed at a lower priority level in accordance with the requirements of the contractual statement of work. Accordingly, only design sketches and models were produced (Reference Appendix C) to illustrate the potential design approaches.

Additionally, Section 8.0 describes an optional Rover-mounted sampler scoop (in lieu of the JPL-robotic arm) capable of acquiring small rocks and surface particulate. This system includes a packaging technique for the acquired surface particulate.

7.0 SAMPLE HANDLING TRANSFER

7.1 Study Task Objectives

A sample handling capability will be required through all phases of the sample acquisition, processing, and stowage processes. Some of these functions will be inherent in the design of the previously described subsystems; other sample transfer functions may require additional hardware. Specifically, consideration will be given to the following functions:

- 1) Transfer of the rock and regolith cores through the individual sample preparation/packaging process and ultimate storage in the sample return containers.
- 2) Transfer of the surface acquired small rock and particulate samples and rock crusher produced samples through the individual sample preparation/packaging process and ultimate storage in the sample return containers.

7.2 Design Approach

Design objective (1) above was essentially accomplished by the integrated design approach previously described for the Rover-mounted drill. A handling device such as a Rover-mounted or Lander-mounted robotic arm will be required to transfer the particulate and rock core containers to the sample return containers. Conceptual approaches for this task are illustrated in Appendix C.

Additionally, the optional Rover-mounted sampler scoop described in Section 8.0 partially fulfills design objective (2). A robotic arm will be required to transfer the acquired sample container from the Rover to the Earth return vehicle sample container.

8.0 ROVER-MOUNTED SURFACE SAMPLE COLLECTION SYSTEM

8.1 Study Objectives

A brief study was performed for a simplified Rover-Mounted Sample Collection System. Although not required by the contract statement of work, it was believed that a cursory study was warranted for sizing (power and weight) a system dedicated specifically for acquiring regolith and small rock samples from the surface as an alternative to the more massive and complex robotic arm which has been indicated as a baseline for use on the Rover. The collection system also incorporates a subsystem for packaging the acquired regolith material in a manner similar to the core drill. Small rocks which are acquired by the collection system would presumably be identified by the imagery system and temporarily stored in a bin located on the Rover deck. After the Rover returns to the lander, a mission operations team decision would be made whether to package the rock (using a lander-mounted robotic arm) for earth return, subject the sample to a rock breaking process, or to reject the rock as an earth-return sample candidate.

8.2 Design Approach (Dwgs MRS-300000, 310000, 320000)

The design drawings (Ref Appendix D) illustrate the Rover-Mounted Sample Collection System which consists of three (3) major subsystems:

- 1) Collection Hand
- 2) Transfer Linkage Device
- 3) Regolith Sample Storage

The sample collection hand consists of three (3) fixed "tines" and five (5) movable fingers to restrain small rocks onto the tines during transfer to the sample storage area. The hand is capable of dislodging embedded rocks via a pivoting spur, and grasping and transferring 10-20 centimeter rocks. The tines are open-tubular shaped for collecting surface regolith samples. The sample collection hand incorporates motorized drives for moving the fingers and pivoting the boom, but the required forward/backward movements are accomplished by powering the Rover drive system.

A four-bar transfer linkage mechanism is provided for maintaining the collection hand horizontal during the transfer process, and for pivoting the hand downwards, when required; to obtain a more optimum sampling angle and to deposit the samples in the regolith sample storage subsystem. The hand tilt can be controlled either by a toggle spring or by an electric drive motor.

The Regolith Sample Storage Subsystem consists of 5 or 7 sample storage tubes of 66 cm³ net storage capacity (4.41 in.³) mounted on a carrousel which is rotated by an electric motor to position the tubes as required. Each sample deposited in the tubes is individually separated from the next by small Teflon caps which are pressed in over each sample. The system can accommodate up to 80 separate samples depending on the volume of each sample.

The sample deposit funnel is equipped with a sizing screen to deflect the larger rock samples collected into a rock bin area about the base of the subsystem. Upon completion of the Rover mission, removal of the screen will permit deposition of small rock pieces of the size anticipated to be returned to earth from the larger rock samples after reduction by the lander-mounted rock breaker.

8.3 System Operation

During flight the transfer arm is locked in position above the Regolith Sample Storage Subsystem (RSSS). Upon deployment of the Rover vehicle the locking device is released, allowing the arm to rest against the locking device base. The location and structure of this device ultimately may depend on location of other subsystems on the Rover or it may be incorporated into the top of the RSSS.

When the Rover vehicle has located a rock to be acquired, the vehicle is positioned appropriately and the transfer arm is deployed. The hand is placed in front of or behind the rock specimen depending on the degree to which the specimen is embedded in the surface.

If the rock is deeply embedded, the hand is placed in front of the rock and the Rover is moved backward, allowing the spur on the hand to dislodge the specimen. When this operation is completed, or if the rock is not deeply embedded, the hand is placed behind it and the Rover is moved forward until the digging tines on the hand have moved under it. The fingers are then closed over the rock and the Rover is moved in reverse to free the tines and acquired rock from the surface. The arm rotation motor is then engaged and the specimen is carried over the top of the Rover and positioned over the RSSS. The pivot link drive motor is engaged to tip the hand down to an approximate 60° inclination, allowing regolith sample from the tines to fall into the RSSS. If the pivot link is of the spring activated type, this action will occur as the transfer arm reaches the end of its travel toward the RSSS. The fingers are then opened allowing the rock to fall. The sizing screen on the RSSS will deflect the rock into the Rock Sample Storage area located about the base of the RSSS. If it is suspected that some regolith is clinging to the digging tines or the sizing screen it may be dislodged by continuing the Rover travel. When the sample storage tube is full, the storage tube carrousel is rotated CCW to bring the newly filled tube under the tamper plunger. The tamper capper motor drives the Ball Reversing Nut in the

upper part of the RSSS through one cycle, compressing the sample into the tube and raising the cap transfer finger. The carrousel is rotated CCW to the cap position allowing the cap transfer finger to pull a cap along the cap guide channel above the tube. The tamper capper is again run through one cycle and the cap is forced down into the tube, pushing the sample down below it, leaving space above the cap for the next sample and pushing the cap transfer finger down to the retracted position. At this point, no tube is under the sample funnel so that if any additional regolith should shake free of the screen on the digging tines on the hand it will not contaminate the next sample tube. Surplus regolith in the funnel initially will fall through between the first and second tubes when the carrousel is first rotated.

When the sample tube carrousel has been completely filled and the Rover has returned to the lander, the carrousel alone may be removed from the Rover and returned. The transfer arm is rotated to the sample collection position and the tension link retaining device is activated allowing the top and central sections containing the tamper/capper and both drive motors to be lifted vertically away from the RSSS base. The sample tube carrousel may now be lifted from the base leaving the inner race of the lower carrousel bearing and the bearing balls behind. Inverting the carrousel will allow the upper carrousel bearing balls to fall out leaving only the sample tubes, carrousel base and two bearing outer races to be returned with the soil and rock samples. The use of angular contact, separable, thin section ball bearings permits this minimization of nonessential hardware in the return package.

8.4 System Mass

The Rover-mounted Surface Sample Collection System was designed for minimum mass and complexity dedicated totally for acquiring surface-level regolith and small rock samples. It uses Rover capabilities where possible, specifically, the forward/backward driving modes are used for pushing and pulling the sampling hand.

Table 8-1 provides a simple mass breakdown for the collection system.

Table 8-1 Rover-mounted Surface Sample Collection System Mass

Drawing	Title	Mass (Kg)
MSR-31000	Sample Collection Hand	2.7
MSR-3200C	Regolith Sample Storage	5.5
N/A	Electronic Sequencing Unit	<u>2.5</u>
	TOTAL	10.7

8.5 Robotic Arm Assessment for Mars Rover

The impact of weight and power on the Rover vehicle by including a robotic arm is substantial. An assessment of types and number of tasks which may be assigned a general purpose manipulator is necessary to justify such a penalty.

Martin Marietta designed and built the first general purpose manipulator for company use in 1974. This manipulator, shown in Figure 8-1, is operated in the fully automatic mode as well as direct man operated from a remote site. The arm measures 5.5 meters (18 ft.) from shoulder pitch to wrist pitch and is capable of applying 6.8 kilograms (15 lbs.) tip force with the arm extended. It has seven degrees of freedom plus end effector which qualifies it for the general purpose classification. Extensive counterbalancing was provided for one "g" operation to permit full utilization of joint drive capacity for work to be performed. Otherwise, drive capacity requirements become excessive due to torques generated by the mass of the arm if counterbalancing is not incorporated.

A second prototype-flight robotic arm was designed and built for MSFC (Huntsville) which is pictured in Figure 8-2. This arm, delivered under Contract NAS8-31487, measures 2.4 meters (8 ft.) from shoulder pitch to wrist pitch and is capable of applying 6.8 kilograms (15 lbs.) tip force with the arm extended. It also is counterbalanced for maximum performance capability in one "g". The counterbalance equipment could be removed prior to launch for subsequent zero "g" flight operations.

A third robotic arm, Integrated Orbital Servicing Unit developed under contract NAS8-30820 is shown in Figure 8-3. This arm is not a general purpose manipulator but dedicated to satellite servicing in space. It too is counterbalanced for one "g" operation and is totally automated.

This experience has shown the necessity for high precision, zero backlash, low friction drives so that automated control can provide the dexterity and accurate positioning necessary for useful performance.

A brief mass assessment was made for a comparable robotic arm for the Mars application based on this previous experience. Expected characteristics of a strawman robotic arm would be as follows:

Length:	1.5 meters (shoulder pitch to wrist pitch)
Degrees of Freedom:	6
Tip Force: (arm extended)	1.5 Kg
Position Accuracy:	± 15 arc minutes
Operating Rate:	60 per second
End Effector:	Special design (Depending on tasks)
Estimated Mass:	27 Kg

It can readily be seen that an excessive mass and power penalty will be incurred in the addition of the robotic arm to the Rover vehicle which must be traded against total utilization of the system capabilities. This penalty should be assessed separately if the arm is located on the lander vehicle.

At this time it seems that with the exception of sample transfer from the Rover vehicle to the lander, sample collecting on the Rover is adequately covered with the special equipment described herein. Unless a substantial number of other tasks are identified requiring a general purpose robotic arm, it is not recommended for use on the Rover.

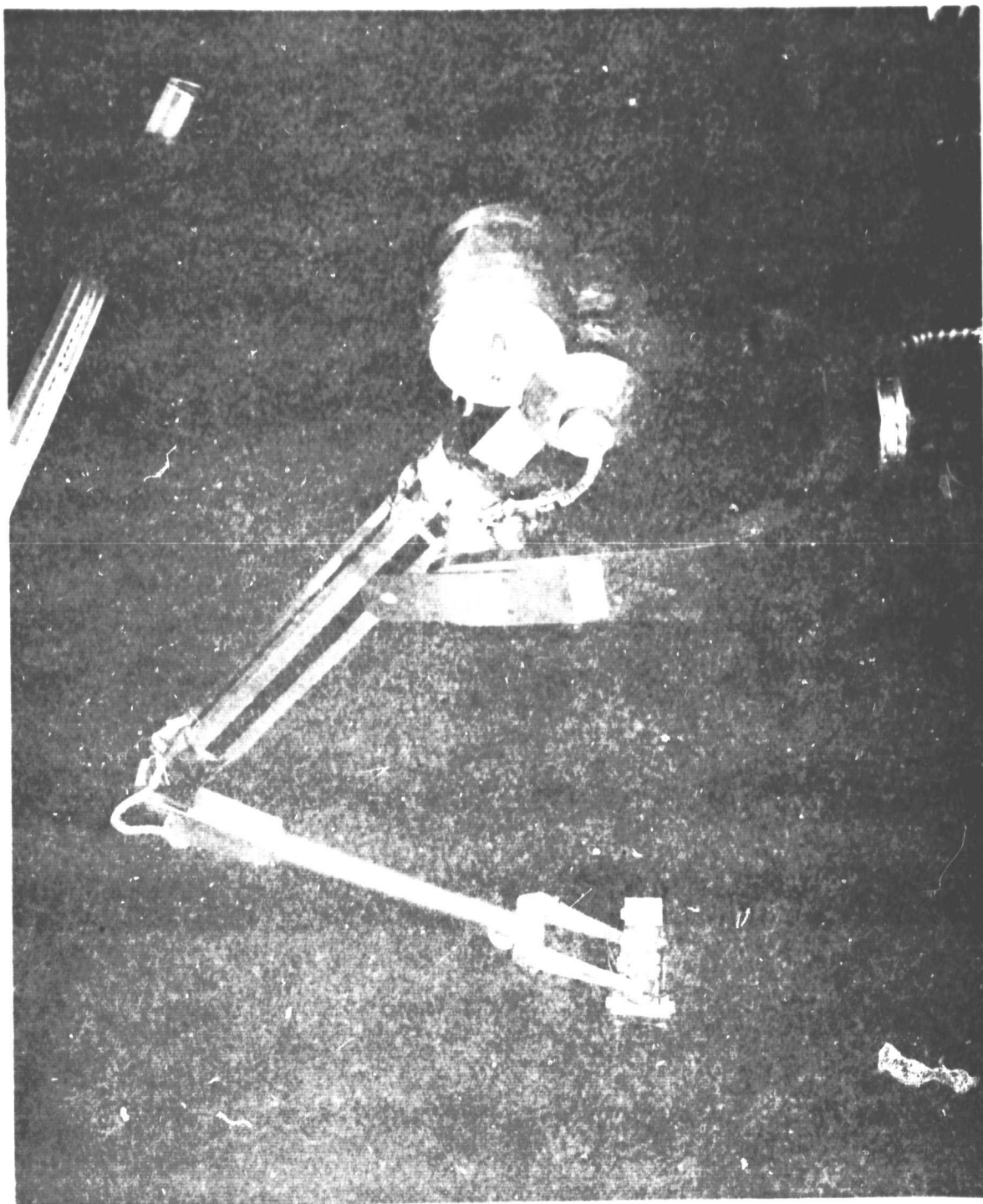


Figure 8-1 General Purpose Manipulator Arm

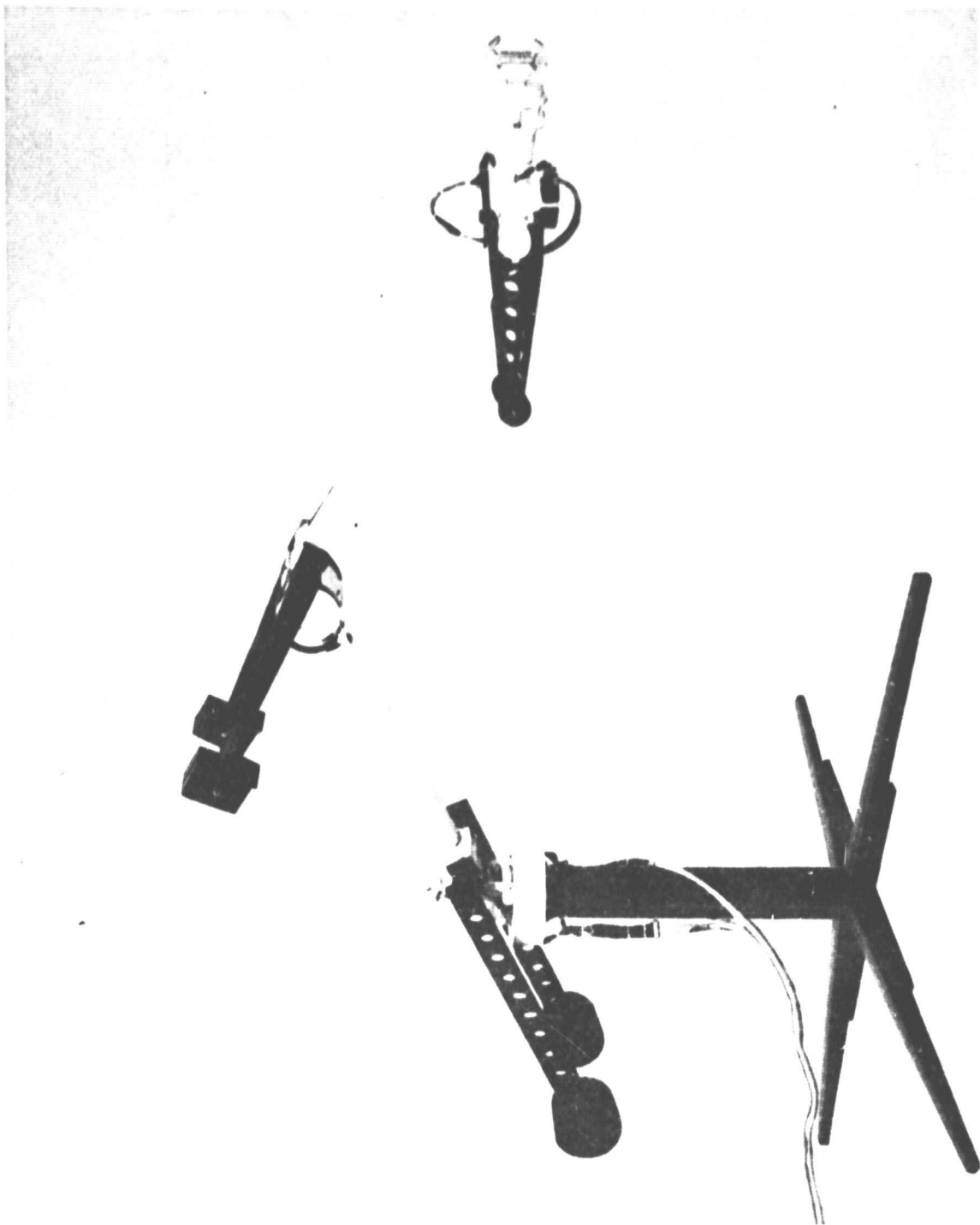


Figure 8-2 Protoflight Teleoperator Retriever Robotic Arm

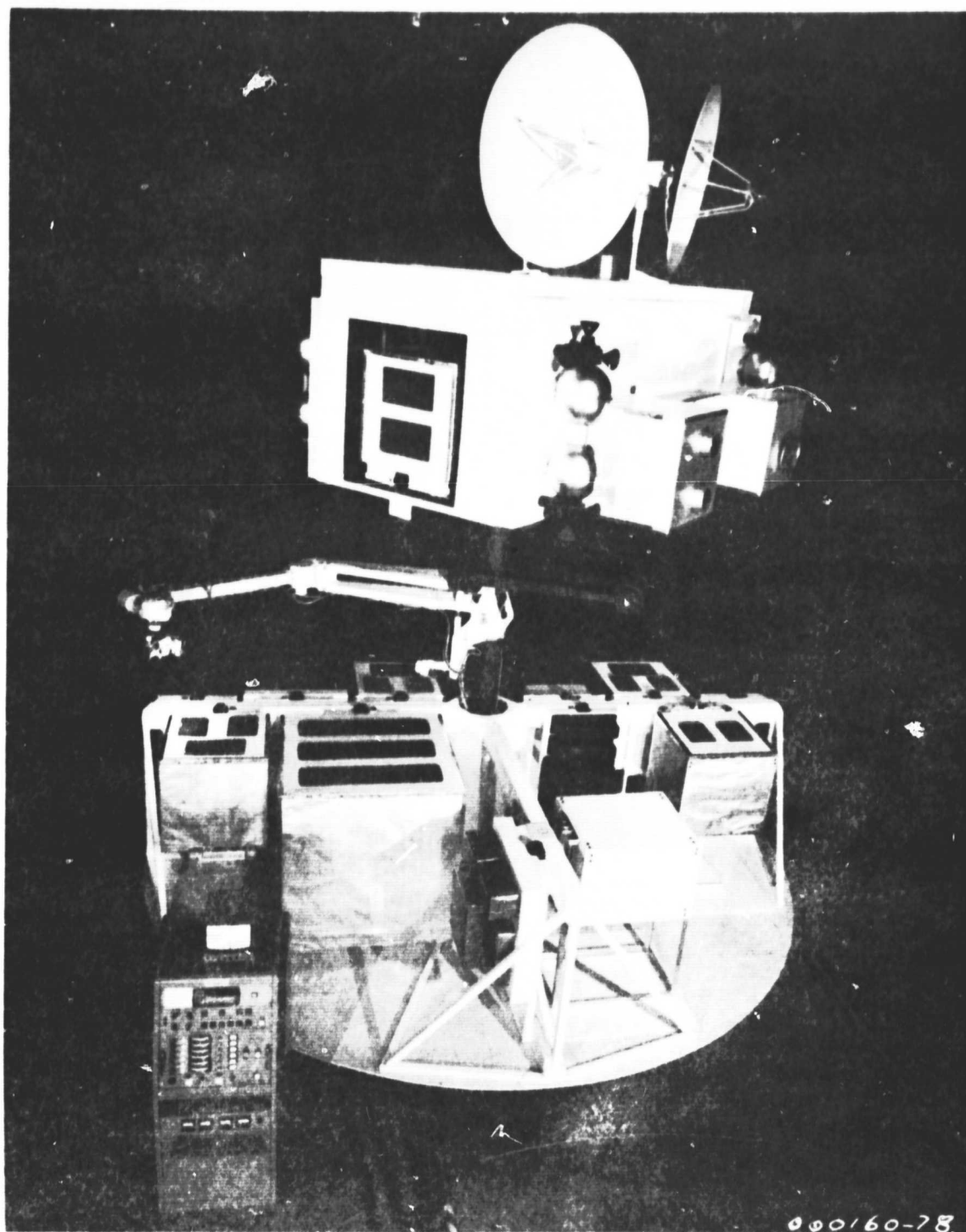


Figure 8-3 Satellite Servicing Robotic Arm

9.0 SAMPLING SYSTEMS POWER REQUIREMENTS

9.1 Study Objectives

A brief study was performed to assess power requirements for the various sampling systems investigated for this study and to provide recommendations for inclusion in the overall Rover power system analysis which eventually must be performed at a system level.

9.2 Power Requirements

The largest power user of the sampling systems studied is the Rover-mounted core drill with its various regolith and rock core packaging devices. Operation of the power head results in the highest peak power demand. This peak power demand can be reduced at the expense of increased drilling time, i.e., the total energy expended remains relatively constant for a specific drilling task such as coring a 1-centimeter diameter, 10-centimeter long core from a 5% porosity basalt rock. As previously discussed, there are limits regarding the minimum allowable peak power for the drill because of the lower energy "threshold" required for rock drilling. Percussive drilling energy levels below a certain threshold will result in essentially "0" penetration regardless of the length of the drilling time.

For purposes of this study it will be assumed that some scale-down from the peak energy requirement of the lunar drill can be accomplished without dropping below the minimum energy threshold for drilling - however, this must be verified by test. Accordingly, Core Drill System No. 3 (Ref Table 3-3) with a power operating level of 236 watts (50% of the lunar drill) was used for purposes of this power requirement analysis. The computed drilling penetration rates for this system with a recommended de-rating included the following:

<u>Drilling Material</u> <u>(Core Size)</u>	<u>Drill Rate</u> <u>(cm/min)</u>	<u>De-Rated</u> <u>Drill Rate</u> <u>(cm/min)</u>
5% Porosity Basalt (1 cm core)	2.5*	1.2
40% Porosity Basalt (1 cm core)	8.0*	4.0
Dry Regolith (1.9 cm core)	25	12.5

*Note: A 50% derating of penetration rate is assumed because of the non-optimum core bit thrust available from the restraint of a 125 Kg Rover operating in the Mars 3/8-G gravitational force field (Ref Figure 3-4).

Table 9-1 provides a summation of the energy requirements for acquiring and packaging of a typical 10-centimeter core from 5% porosity basalt and a 1-meter core from a dry regolith surface. It can be calculated from the table that the demand on a Rover 30 VDC power system will be 31.3 watt-hrs for each rock core sample, and 18.1 watt-hrs for each regolith sample.

Table 9-2 provides a similar summation of the energy requirements for the Rover Surface Sample Collection System. It can be calculated from the table that 8.3 watt-hrs will be required for each surface sampling sequence.

Table 9-2 Rover Surface Sample Collection System Power Requirements

Operation	Time (Sec)	Power (Watts)	Total Energy (Watt-Sec)
Arm Deploy	530	9.5	5,035.0
Finger Close	4	3.1	12.4
Arm Transfer	530	10.5	5,565.0
Pivot Hand	37	3.1	114.7
Finger Open	4	3.1	12.4
Pivot Hand	37	3.2	118.4
Index RSSS	12	3.6	43.2
Operate T/C	53	9.5	503.5
Index RSSS	24	3.6	86.4
Operate T/C	53	9.5	503.5
Index RSSS	2	3.6	7.2
Electronic Sequencer	1286	14.0	18,004.0
TOTAL			30,005.7 (8.3 Watt-Hr)

It is presumed that a RTG-battery combination will be used for the Rover power system. It can be calculated from the sampling energy requirement data described above that the battery energy replacement from a 25-watt RTG with an 80% charging efficiency will require the following battery recharge time for each acquired sample:

Sample	Acquisition Time/Sample (Hr)	Battery Recharge Time/Sample (Hr)
10-cm Rock Core	0.4	1.6
100-cm Regolith Core	0.2	0.9
Surface Sample	0.4	0.4

Table 9-1 Rover Core Drill System Power Requirements

Mechanism	Globe Motor Equivalent	Current (Amps)	RPM	Rate (cm/min)	Time/Sample (sec)	Amps-Seconds	
						Rock	Regolith
<u>Core Drill Positioning</u>							
Rotation Mech	102A203-10	1.4	6.0	N/A	6 (+90°)	8.4	8.4
Linear Drive	5A2317-11	0.28	14.0	30.5	60	16.8	16.8
<u>Power Head Linear</u>							
Translation	102A208-10	1.4	1.2	41.9	584 (Rock) 344 (Reg)	817.6	481.6
<u>1-Meter Drill Storage</u>							
Rotation Mech	5A2317-11	0.25	14.0	N/A	6 (+90°)	-	1.5
<u>Regolith Hdlg Mech</u>							
Linear Drive	5A2317-11	0.25	14.0	3.0	400	-	100.0
Turret Drive	5A2320-11	0.25	6.4	N/A	20	-	5.0
Pivoting Arm Drive	5A2320-11	0.25	6.4	N/A	10	-	2.5
<u>Rock Core Hdlg Mech</u>							
Linear Core Removal	5A2317-11	0.25	14.0	3.0	600	150.0	-
Linear Cap Drive	5A2317-11	0.25	14.0	3.0	300	75.0	-
Turret Drive	5A2320-11	0.25	6.4	N/A	20	5.0	-
Pivoting Arm Drive	5A2320-11	0.25	6.4	N/A	10	1.5	-
<u>Power Head Drive</u>							
Rotary Percussion	Special	7.9	272	N/A	240 (Rock) 143 (Reg)	1896.0	1129.7
<u>Release Devices</u>							
Regolith Turret Rel	851G & H	4.5 (3 Milli-Sec)			Negligible		
Regolith Bridge Rel	2 Explosive Nuts	5.0 (5 Milli-Sec)			Negligible		
Rock Core Container	8002 G & H	4.5 (5 Milli-Sec)			Negligible		
<u>Electronic Sequencer</u>							
Electronic Quiescent	Special	0.5			1580 (Rock) 846 (Reg)	790.0	423.0
TOTALS						3760.3	2168.5

9.3 Potential Power System

9.3.1 General Approach

It is not within the scope of this contract to perform a total Rover system-level power requirements analysis and to recommend a potential power system. Power-using subsystems such as thermal control, Rover mobility power, command and data management, RF transmitter-receivers, etc. were not considered. However, a preliminary assessment of recommended power systems for the surface sampling hardware is appropriate, and some of this data will be equally applicable to the other Rover subsystems.

The peak power demand of the Rover core drill will occur during rock or regolith drilling when the electronic control sequencer, power head, and power head linear translation drive system are operating simultaneously. This cumulative power demand on a 30 VDC system will be as follows:

<u>Subsystem</u>	<u>Power (Watts)</u>
Electronic Control Sequencer:	15
Power Head (System No. 3):	236
Power Head Translation Drive:	<u>42</u>
TOTAL:	293

The 293 watts is obviously higher than the capability of any reasonable size RTG. However, it is doubtful that this power demand will "drive" the Rover power system design since the power required for Rover mobility and RF transmission will also be much higher than can be provided by a reasonable size RTG.

A reasonable power system for the Rover will probably consist of a RTG (i.e., 25-50 watts) and a storage battery for providing the higher energy required for peak power demands. The RTG recharges the battery during periods when the Rover power demand is less than the output capability of the RTG.

Figure 9-1 illustrates a potential power system for the Rover. It basically consists of the RTG, DC/DC converter for "stepping-up" the low voltage output of a typical RTG which may be of the order of 4-8 VDC, voltage regulators, batteries, and battery charge control units.

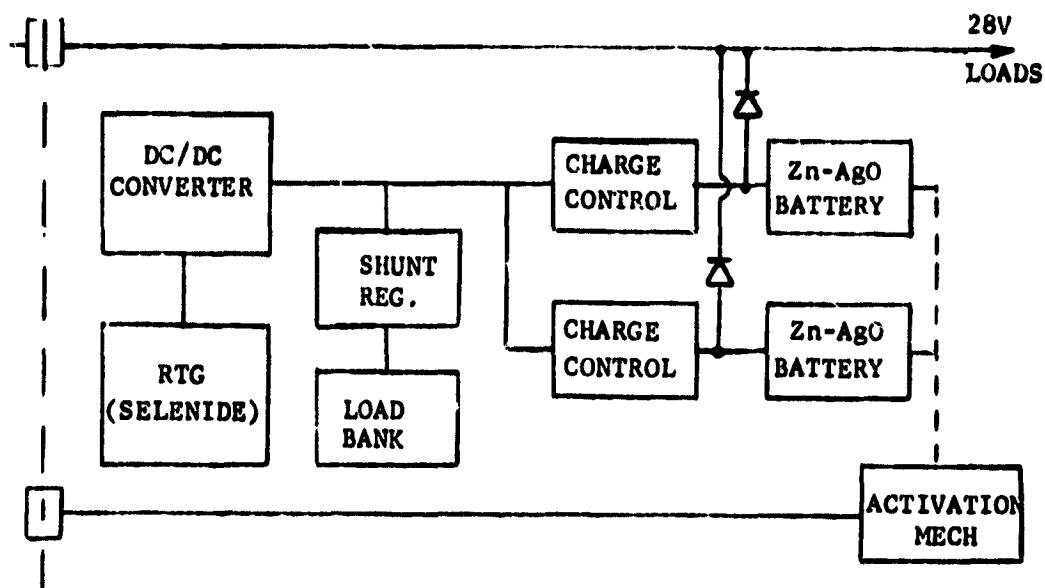


Figure 9-1 Potential Rover Power System

9.3.2 Batteries

Figure 9-1 suggests the possible use of lighter weight, primary-type, silver-zinc batteries with remotely operated electrolyte activation systems. Such systems are expected to provide energy densities of 66 watt-hr/kg (30 watt-hr/lb) in the 1985-1990 time-frame due to technology improvements by companies such as Eagle Pitcher and Yordney Electric. A 300 watt-hour battery weighing 4.5 kg (10 lbs) would be quite adequate to meet surface sampling requirements although it may be somewhat small for the other Rover subsystem power demands. A 300-watt-hour, primary-type silver-zinc battery was successfully used with the Lunar Surface Drill for Apollo missions 15, 16 and 17. However, the typical 60-100 day "wet life" of the primary-type silver zinc batteries anticipated for the 1985-1990 time frame will be inadequate for longer duration (6 months - 1 year) Rover traverse missions.

Long wet-life batteries (activated prior to launch) such as the NiCds used on the Vikings are also applicable to the Rover. The Viking battery assemblies each contained two (2) 8-ampere hour batteries (480 watt-hrs-total) weighed 22.9 kg (50.5 lb), which provided an energy density of 20.9 watt-hr/kg (9.5 watt-hr/lb.). This battery, with its 5-years of space and Mars surface performance history would be a candidate for a Rover mission.

Consideration should also be given to the new lithium batteries which have demonstrated energy densities up to 440 watt-hr/kg (200 watt-hr/lb). These batteries are currently being considered for the Galileo program. However, some of their characteristics such as high internal impedance and low discharge rates make them less desirable than the AgZn and NiCd batteries.

9.3.3 Radioisotope Thermoelectric Generator (RTG)

The state-of-the art technology for RTGs which may be applicable to a Rover mission is improving. The Viking RTGs are characterized as follows:

Type:	SNAP-19
Thermal Power:	675 watts
Electrical Power:	>35 watts
Electrical/Thermal Efficiency:	5.2%
Weight:	15.4 kg (34 lbs)
Specific Power:	2.2 watt/kg (1 watt/lb)

Significant improvements in RTG technology are being predicted by manufacturers such as Teledyne Ryan. These improvements are based upon using selenide thermoelectrics and plutonium dioxide (PU 238 O₂) as a fuel. The following improved efficiencies are being predicted.

Year

1983	Electrical/Thermal Efficiency: 11%
	Specific Power: 7.7 watts/kg (3.5 watts/lb)
	Cost: \$15-25 K/watt
1985	Electrical/Thermal Efficiency: 13.5%
	Specific Power: 8.8 watts/kg (4.0 watts/lb)
	Cost: \$5 K/watt

The RTG data was provided as an indication of future trends in terms of efficiency, specific power and cost. A total Rover power system analysis is required before specific RTGs can be selected.

10.0 CONCLUSIONS AND RECOMMENDATIONS

10.1 Sampling Equipment For Mars Sample Return Missions

The top-level, rather detailed design configurations developed for the automated Rover-mounted rock and regolith core drill, rock breaker, and surface sample collection system indicate the feasibility of using such devices on future Mars missions. The accompanying mass and power requirements to perform the tasks requested by the scientific community are higher than desired, but should be accommodable.

The preliminary simulated permafrost drilling tests were not considered to be successful and did not meet the goal of obtaining 1-meter cores using the sampling equipment which would be appropriate for dry regolith and rock cores. However, it is probable that the rock core bits could be used to obtain 10-centimeter cores (in lieu of 1-meter cores) from permafrost-type surfaces.

A potential complement of sampling equipment for a "strawman" Rover mission which would meet the minimum study requirements for a rock coring drill and simple surface sampler includes the following:

<u>Equipment List (Option I)</u>	<u>Mass (Kg)</u>	<u>Pwr/Sample (Watt-Hr)</u>
*Rock Core Drill With Integral Packaging Capability	31.9	31.3
Surface Sampler With Integral Packaging Capability	10.7	8.3
Total	42.6	

* Note: Additional mass reductions are possible (Ref. Table 3-8) but are not recommended

An alternate complement of sampling equipment could be provided which would include the addition of 1-meter regolith core sampling to the basic rock coring device. This equipment includes the following:

<u>Equipment List (Option II)</u>	<u>Mass (kg)</u>	<u>Pwr/Sample (Watt-Hr)</u>
Rock and Regolith Core Drill With Integral Packaging Capability	41.2	31.3 (1-cm Rock)
	-	18.1 (1 M Regolith)
Surface Sampler With Independent Packaging Capability	10.7	8.3
Total	51.9	

A third option consists of using the multipurpose robotic arm and drill system:

<u>Equipment List (Option III)</u>	<u>Mass (kg)</u>	<u>Pwr/Sample (Watt/Hr)</u>
Rock and Regolith Core Drill With Integral Packaging Capability	41.2	31.3 (10-cm Rock)
	-	18.1 (1-M Regolith)
Robotic Arm (With 2.5 kg Electronics)	29.5	-
Robotic Arm Sample Storage (Estimate)	3.0	
Total	73.7	

Other combinations of the Rover-mounted equipment are possible. Additionally, some of the equipment (such as a duplicate regolith drill) can be mounted on the Lander.

The Martin Marietta equipment allocation recommendation is as follows:

Rover: Option II (Rock/Regolith Drill and Surface Sampler)

Lander: Robotic Arm and Rock Breaker

10.2 Follow-On Study Recommendations

It is recommended that some advance technology tasks be authorized to proceed to the next level of design and development detail required before a more accurate assessment of equipment capability, mass, and power can be made. Specifically, the following tasks are recommended:

- 1) Design, fabricate, and test an engineering "breadboard" core drill system using the baselines established during this study.
- 2) Perform a more extensive study (Ref. Para. 4.6) of the problems and solutions to permafrost drilling if Rover sorties to the Mars polar regions are still being considered.

The technology tasks suggested above are equally applicable to other programs in the advance planning stages such as probes to Saturn's moon, Titan, the back side of the moon, and the comets.

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CCREL - U.S. Army Cold Regions Research and Engineering Laboratory

APPENDIX A

CONTRACT STATEMENT OF WORK

1.0 INTRODUCTION AND GUIDELINES

Studies regarding a future Mars sample return mission are now in progress. Preliminary guidelines have been established for surface sampling which should be used as a baseline for this study. These guidelines include, but are not limited to, the following:

1.1 Multiple crystalline rock samples will be obtained from a roving vehicle whose mass and power capabilities are limited. Preliminary designs have placed the total rover vehicle mass at 125 kg and average power output at 20 watts. Greater power output will be possible for durations of 15-20 minutes, e.g., 200-300 watts. Consider for design purposes 20 to 30 ten cm length cores.

1.2 The crystalline rock drill system will be capable of operating at drilling angles varying between vertical and horizontal to the local surface, and drilling cores from small (5 - 10 cm) rocks which must be restrained on the surface or which are contained in a rover-mounted restraining device. The hardness of the rock cores will be similar to that of crystalline basalt with porosity in the range of 5 to 40 percent.

1.3 One or more regolith samples will be obtained at each landing site by a drill system mounted on the descent stage which will be capable of drilling approximately 2 cm diameter cores to depths of 1 - 2 meters. The number of samples to be acquired and returned to Earth has not been determined, but approximately 3 - 5 regolith cores should be considered for design purposes. Techniques for retaining all or portions of regolith cores and minimizing escape of volatiles during acquisition and encapsulation will be required.

1.4 The regolith cores may require drilling through permafrost and subsurface rocks.

1.5 Sample contamination must be kept to a minimum; contribution from the sampling devices must be known, and contamination between samples (cross contamination) must be minimized.

1.6 A rover-mounted articulated or furlable boom or simple scoop/rake will be used to pick up small rock samples and surface material and perhaps assist with the transfer of samples from the drill to the sample return container. Documented surface samples and small rocks will be packaged in individual containers prior to stowage in the sample return container.

1.7 A sample return (to Earth) payload of 2 - 5 kg is anticipated.

1.8 Maximum target weight for the rover drill, sampler/scoop sample handling and storage is 25 kg.

1.9 Additional equipment which may be required includes a rock breaker.

1.10 The contingency sampler will be located on the lander and may also be used to aid in the sample container transfer and/or to acquire the regolith core described in item (1.3) above.

2.0 STUDY TASKS

A series of tasks will be performed to demonstrate the feasibility of acquiring various surface samples for a Mars sample return mission. The guidelines described in Section 1.0 will be used as a basis for the tasks. Specific study tasks should be independent of any conceptual design for a roving vehicle or for the descent or ascent vehicles.

Tasks 2.1, 2.2, and 2.3 are listed in order of decreasing priority. The tasks should be worked and completed in series unless the contractor feels the quality of work would be enhanced by parallel efforts, and that a reasonable confidence exists for their completion. Tasks 2.4 and 2.5 are vehicle design dependent, and, as such, should be given conceptual design consideration only; no prototype development should be attempted.

2.1 Rover-Mounted Drill System

The drill system will be capable of producing 10 cm length cores from 5% porosity and 40% porosity basalt. The system will be automated such that it can operate from digital sequence command loads stored in a (rover) computer. Control electronics will be required to operate between the computer and the drill system. Consideration will be given to the following functions:

a. Assess the optimum drilling technique for the acquisition of crystalline rock cores. The assessment should include, but not be limited to, rotary-percussion, rotary, impact, and ultrasonic drilling technique.

b. Drilling forces, speeds, percussion impact energies, power requirements vs drill penetration rate, and, if possible, sample temperature vs penetration rate.

c. Drill bit and stem configuration. There is a desire to obtain a large number of crystalline rock cores. Since there will be a limitation in sample volume and mass returnable from Mars, there is a desire to decrease the ALD core diameter from 1.9 cm to a value closer to 1.0 cm. If bit wear or survivability is a concern, consider separate, expendable bits for each core sample.

d. Provide a matrix showing performance versus significant increases in power/mass for the proposed system(s).

e. Rock core sample retrieval. Develop a technique for the removal of a core from the host rock and, after that, removal of the rock core from the core drill stem. Since sample containment and contamination is a concern, consider a tubular insert for the drill stem which could be extracted and hermetically sealed on one or both ends.

f. Minimum sample size. Determine the minimum size of rock which can be cored either by restraining the rock on the surface, or by restraining it onboard the rover vehicle.

2.2 Simulated Permafrost Coring Tests

a. Determine the feasibility of obtaining subsurface regolith cores including the possibility of coring regolith (lunar and/or Martian simulant) saturated with frozen H₂O and CO₂, and the feasibility of coring H₂O and CO₂ ice which is devoid of particulates.

b. Provide a matrix showing any increased capability possible with the proposed system(s) with additional power and length of drill string.

2.3 Rock Breaker System

It is anticipated that a rock breaker device, as distinct from a crusher, will be required to produce smaller rock samples from rocks too small to core. The "minimum sample size" defined in the effort described in 2.1f should be the largest specimen tested in this application. Consideration will be given to the following:

- a. Reduction of a specimen to sizes ≤ 2 cm in diameter
- b. Estimation of reduced sample mass
- c. A technique for purging the device in preparation for a new sample.
- d. Determination of the best location for the device, i.e., rover, descent stage, etc.

2.4 Sample Containment

Sample containers will be required for the selected regolith cores, rock cores, and the small particulate and rock samples acquired from the surface and from the rock breaker. Additionally, a larger sample

container(s) will be required to transport all individual samples acquired on the surface of Mars to Earth. Consideration will be given to the following functions:

- a. A technique and conceptual design for packaging the selected regolith cores or portions thereof in hermetically sealed, identified containers.

- b. A technique and conceptual design for packaging the rock cores in identified containers.

- c. A technique and conceptual design for automatic or semiautomatic packaging of the small rocks and surface particulate samples in identified containers.

- d. A conceptual design for the Mars-to-Earth sample return container(s). Consideration should be given to optimum configuration for maximum storage capacity, maintaining all of the samples at the Mars ambient temperature or lower.

2.5 Sample Handling Transfer

A sample handling capability will be required through all phases of the sample acquisition, processing, and stowage processes. Some of these functions will be inherent in the design of the previously described subsystems; other sample transfer functions may require additional hardware. Consideration will be given to the following functions:

- a. Transfer of the rock and regolith cores through the individual sample preparation/packaging process and ultimate storage in the sample return containers.

- b. Transfer of the surface acquired small rock and particulate samples and rock crusher produced samples through the individual sample preparation/packaging process and ultimate storage in the sample return containers.

3.0 REPORTS

The contractor will prepare informal quarterly letter reports and a final report at the conclusion of the program.

Output of the Study Tasks will include conceptual designs, drawings, performance characteristics, weight, and power estimates.

APPENDIX B

SCIENTIFIC COMMUNITY SURVEY OF MARS SAMPLING REQUIREMENTS

1.0 SURVEY FORM

A simple one-page form was generated for submittal to members of the planetary scientific community in June 1978, under NASA Contract NAS9-15163. This form requested information regarding the nature of the proposed scientific experiments to be performed on the returned samples, types of core samples required (i.e., rock or regolith), geometry of the returned samples, special requirements, etc. These forms, along with appropriate cover letters from Dr. Michael B. Duke (Chief of the Lunar and Planetary Sciences Division at the NASA Johnson Space Center), and Mr. D. S. Crouch, the Martin Marietta Program Manager, were submitted to approximately 2300 members of the planetary scientific community. The listing for these scientists and engineers was provided by the Johnson Space Center. A copy of the form and letters used for this are attached.

2.0 SURVEY RESULTS

A total of 92 responses to the questionnaire were received. Of these responses, 62 responded directly to the potential core sample requirements for both particulate and rock material. A breakdown of these responses at *this level* includes the following:

13 individuals interested in *rock cores* only;

19 individuals interested in *particulate cores* only;

30 individuals interested in both *rock* and *particulate* cores.

A small number of responding individuals expressed a specific interest in sampling of permafrost in the polar regions and most of these individuals were rather strong in their convictions. It is anticipated that additional polar sample requests would have been received if the survey form and background letters had addressed the possibility of a polar-roving vehicle. Although only six individuals expressed an interest in biologically related experiments, this particular scientific community listing consisted primarily of geology-interested members. A similar sampling strategy survey of the biology-interested scientific community is being planned by Ames Research Center.

A variety of comments were received from the 30 individuals who did not respond directly to the potential core sample requirements. Approximately eight were *out of the space business*, *retired*, or *had no opinion*. The remaining 22 would be satisfied with *surface samples* (rock and particulate), or proposed other experiments either *indirectly related* to drilling

(i.e., seismic sensors, water analyzer, in situ subsurface dielectric measurements), or indirectly related to the mission (i.e., solar wind collector).

Table B-1 presents a summary of the 62 responses regarding rock core and regolith core requirements. It is interesting to note that 24 individuals requested that either (or both) a pressure and temperature control be provided for the return samples. These requests ranged from the difficult requirement of *complete maintenance* of Mars sample acquisition pressure and temperature to the rather lenient requirement of permitting temperature rises up to 500°C. Several other *special requirements* were requested and are not specifically listed in the table since they are obviously inherent with any future Mars sampling mission. These included requirements such as avoidance of terrestrial contamination, avoidance of sample mixing, sampling from each major unit, minimum sample disturbance, and photodocumentation of all sampling sites. Several responses requested that an "undisturbed" regolith sample be returned and techniques for providing such a sample were suggested.

Table B-2 provides a summary of categories of proposed experiments to be performed on the returned samples of in-situ experiments using the core holes. The complete collection of responses has been provided to the NASA for their continued evaluation.

Table B-1 Survey Summary of Drill Core Requirements

Characteristic	Responses for Rock Cores	Responses for Regolith Core
<u>Diameter</u>		
< 1 cm	2	2
1 - 2.5 cm	36	34
> 2.5 cm	2	6
No Preference/No Comment	22	20
<u>Core Depth</u>		
< 10 cm	10	4
10 cm - 1 m	17	16
1 - 2 m	3	10
> 2 m	7	9
No Preference/No Comment	25	23
<u>Number of Holes</u>		
< 5	16	21
5 - 15	17	14
> 15	5	7
No Preference/No Comment	24	20
<u>Separation Distance</u>		
< 3 m	7	4
3 - 500 m	11	9
> 500 m	10	18
No Preference/No Comment/ Real Time Judgment	34	31
<u>Number of Samples</u>		
< 5	8	13
5 - 20	17	13
> 20	11	13
No Preference/No Comment	26	23
<u>Size (Volume)</u>		
< 1 cc	19	21
1 - 10 cc	13	12
10 - 100 cc	3	2
> 100 cc	2	4
No Preference/No Comment	25	23
<u>Special Requirements</u>		
● Maintain Temperature and/or Pressure Control	19	24
● No Preference/No Comment	43	38

Table B-3 Survey Summary of Proposed Experiments

RETURNED SAMPLE ANALYSES														IN-SITU ANALYSIS						
Analysis Technique Sample Type	Petrology/Petrography				Exo- biology	Mechanical/Physical Properties							Water	Density/Physical Properties	Inorganic Chemistry	Grain Morphology	Optical			
	Inorganic Chemistry (incl. volatiles)	Mineralogy (incl. phase equilib. thermodynamics)	Fabric/Texture/Grain Morphology	Trace Element/Isotopic Composition	Undefined	Organic Chemistry	Paleontology	Acoustic Velocity	Density	Strength	Stratification	Thermal						Electrical	Magnetic	Optical
Regolith	8	2	4	4	3	4	2	2	5	4	6	3	3	2	2	2	2	1	2	
Rock	5	3	2	2			1	1	1	1		2	2							
Regolith/ Rock	26	15	13	5	1	5	2				1			1			2		2	

NOTE 1:

The JSC-furnished listing used for this study primarily contained scientific community members who are interested in the geological aspects of the Mars mission; inputs from a biological requirements study being performed for Dr. R. S. Young of NASA Headquarters, Chief of Planetary Biology, by NASA Ames Research Center will be included at a later date.

NOTE 2:

In addition to the in-situ measurements identified during sample collection, some investigators would like to see instruments employed in the vacant core holes. These experiments include seismic, electrical, and thermal conductivity.

NOTE 3:

One investigator suggested using the transport vehicle from earth to Mars and return as an ideal platform for measuring the composition of the interplanetary medium outside of the earth-moon system.

NOTE 1: The JSC-furnished listing used for this study primarily contained scientific community members who are interested in the geological aspects of the Mars mission; inputs from a biological requirements study being performed for Dr. R. S. Young of NASA Headquarters, Chief of Planetary Biology, by NASA Ames Research Center will be included at a later date.

NOTE 2: In addition to the in-situ measurements identified during sample collection, some investigators would like to see instruments employed in the vacant core holes. These experiments include seismic, electrical, and thermal conductivity.

NOTE 3: One investigator suggested using the transport vehicle from earth to Mars and return as an ideal platform for measuring the composition of the interplanetary medium outside of the earth-moon system.

National Aeronautics and
Space Administration



Lyndon B. Johnson Space Center
Houston, Texas
77058

Reply to Attn of **SN7-78-L185**

**Members of the Planetary
Science Community**

Dear Colleague:

As you know, we have been working toward a Mars Sample Return Mission for the mid- to late-1980's. Enough progress has been made so that your help is now needed. First I will bring you up to date concerning the developing Mars program.

For the past year the Mars program has been carried as a joint venture between the Jet Propulsion Laboratory (JPL) and the Johnson Space Center (JSC). JPL has been performing the spacecraft design and mission analysis studies while JSC has been working on the science requirements and objectives. This total effort has been guided by a small steering group chaired by Arden Albee of Cal Tech. The prime objective of the past year's efforts has been to explore all options of Martian exploration. In that context several vehicles have been studied, including orbiters for communication and/or scientific observation, soft landers, hard landers, penetrators, sample return vehicles, rolling balls, airplanes, autonomous rovers as landed laboratories, and mini-rovers as sample getters. The potential scientific return of the various vehicles has been evaluated and preliminary cost estimates have been generated as part of the engineering study. Although all cost estimates are tentative, the chief conclusions are that any two-site Mars mission that seeks to answer many of the major scientific objectives concerning Mars will involve several vehicle types and will probably cost between \$1 and \$1.5 billion in constant 1979 dollars.

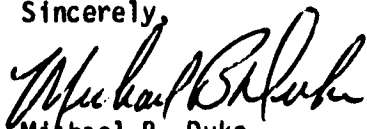
It is a significant finding of the past year's activities that a Sample Return Mission with a scientific orbiter (for global geochemical and geophysical observations) plus a set of hard landers or penetrators (for seismic, weather, and other network observations) costs about the same as a landed roving laboratory with the same associated scientific orbiters, and hard landers (or penetrators). We believe that this finding assures that the next mission to Mars will return Martian samples to Earth for intensive study in laboratories of Principal Investigators throughout the world.

It is clear that drilling will be important in any Mars Sample Return Mission. Cores recovered from the regolith will be essential in studying such processes and phenomenon as weathering, regolith dynamics, and the inventory and storage of volatiles. Core drilling of boulders or outcrops may be the best method of obtaining and returning igneous rocks (remember Viking's inability to collect a small igneous rock), which are essential as calibration points in Martian chronology and to understand the internal evolution of the planet.

We are funding Don Crouch of Martin Marietta (the people who built the Apollo drill and the Viking arm and scoop) to perform a study aimed at generating a conceptual design for a Mars drill. A portion of that study is to generate a definitive set of drilling requirements.

I request that you take a few moments to complete the enclosed data sheet. The data thus collected will form a key input in defining the requirements for rock and regolith drilling as part of a Mars Sample Return Mission.

Sincerely,



Michael B. Duke
Chief, Lunar and Planetary Sciences Division

Enclosure

MARTIN MARIETTA AEROSPACE

DENVER DIVISION
POST OFFICE BOX 178
DENVER, COLORADO 80201
TELEPHONE (303) 973-3000

June 19, 1978

**Members of the Planetary
Scientific Community**

Dear Colleague:

It is time that we planetary scientists and engineers reflect on the results of surface sampling operations performed on the surface of the moon and Mars in order to visualize sampling requirements for future missions to Mars. Bulk particulate samples, surface rocks, 40-65 centimeter drive-tube particulate cores and 3-meter powered drill cores were acquired on the lunar surface by the Apollo astronauts and returned to Earth. Samples from the surface of Mars were acquired by a maneuverable boom/collector head and analyzed by experiments located within the Viking lander. Although the Viking samplers performed exceedingly well for nearly two years on the Martian surface, there were occasions when the various principal investigators would have desired to acquire samples at depths greater than the 20-centimeters attained by the samplers.

I am sure that many of you, in retrospect, may have employed alternate approaches to the lunar and Mars sampling tasks. I served as the Martin Marietta project engineer for both the Apollo Lunar Drill and Viking Surface Sampler programs, and, in retrospect, would also have modified some of the design approaches employed in the flight hardware.

We are currently performing a small study program directed at determining potential sampling requirements and mechanization approaches for future Mars missions. The enclosed letter prepared by Dr. Michael Duke of the Johnson Space Center outlines some of the potential future Mars missions currently being studied by the NASA. It is our feeling that we should solicit the thoughts of all members of the planetary scientific community regarding the surface sampling task. Therefore, your preliminary suggestions regarding sampling and coring requirements, mechanization approaches, and sample analyses will be greatly appreciated. A simple form has been prepared for your use. I would appreciate it if you would return it to me as soon as possible to my Martin Marietta address.

Very truly yours,

Donald S. Crouch

Donald S. Crouch
Mail Stop D-0222

FUTURE MAR MISSIONS
DRILL SAMPLER SCIENTIFIC/OPERATIONAL REQUIREMENTS

Request By _____ Date _____

Address: _____

Telephone: _____

Brief Description of Experiment(s): _____

Drill Experiment Sample Requirements:

		Rock Sample (core or drilled)	Particulate Sample (core or drilled regolith)
CORE/HOLE REQUIRE.	Diameter		
	Depth or length		
	No. of holes (cores)		
	Separation distance between holes (cores)		
SAMPLE REQUIREMENTS	Number of samples		
	Size (volume)		
	Special requirements (i.e., allowable T rise, min/max core or particle size, etc.)		
	Other comments		

Auxiliary Drill Experiment (i.e., probe emplacement, surface physical
 properties, etc.): _____

Suggested Earth Analog Test Suite Rocks

Type _____
 Location _____

APPENDIX C

CONCEPTUAL DESIGN SKETCHES AND MODELS

The design efforts performed during this study were preceded by the generation of several design approach sketches illustrating potential techniques for accomplishing the desired operations. Additionally, small models of the Lander, Rover, and associated sample collection/handling hardware were constructed to provide further illustration of the required operations.

The resultant sketches and models are illustrated on the following pages of this appendix.

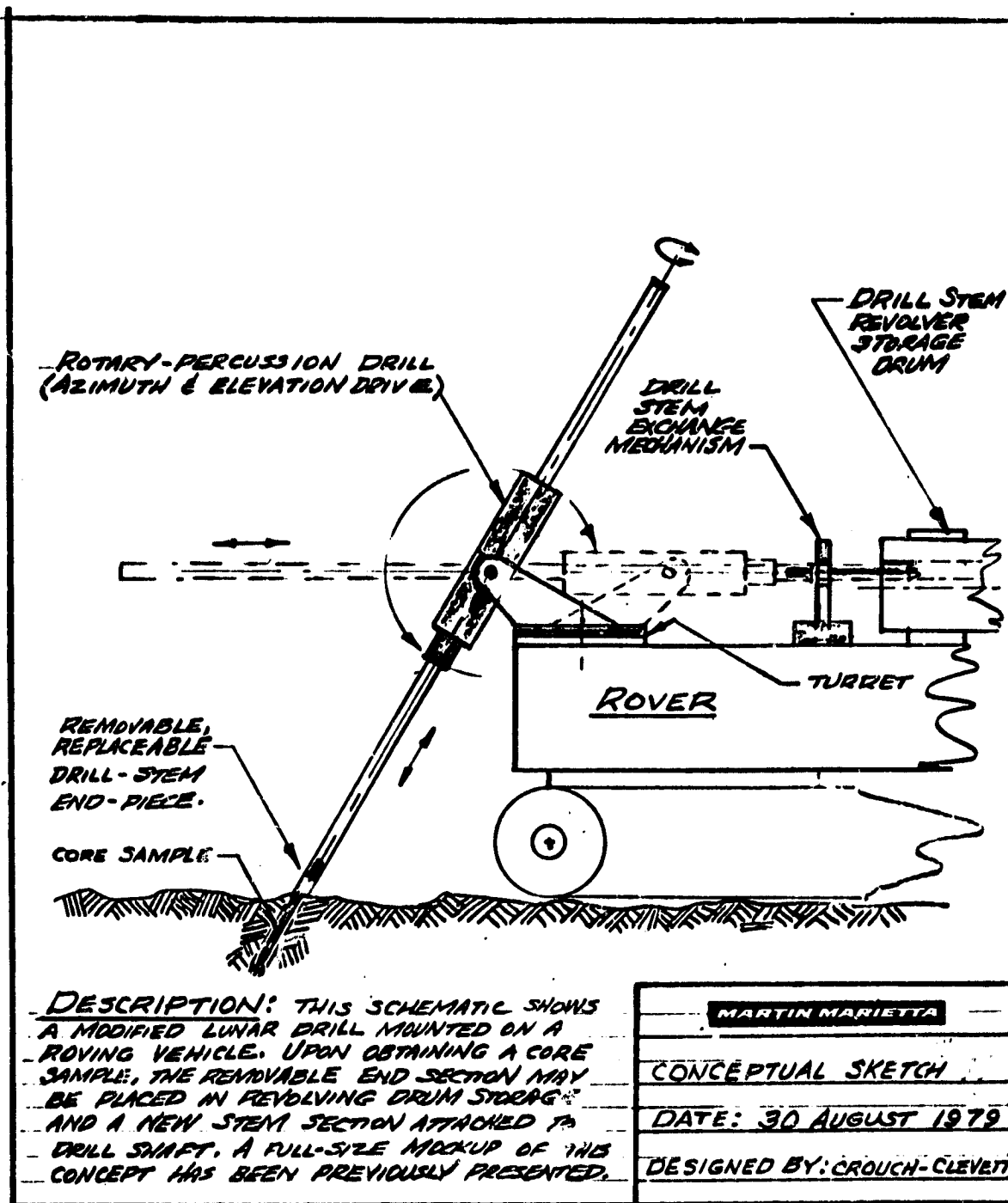


Figure C-1 Sketch - Rover-Mounted Core Drill

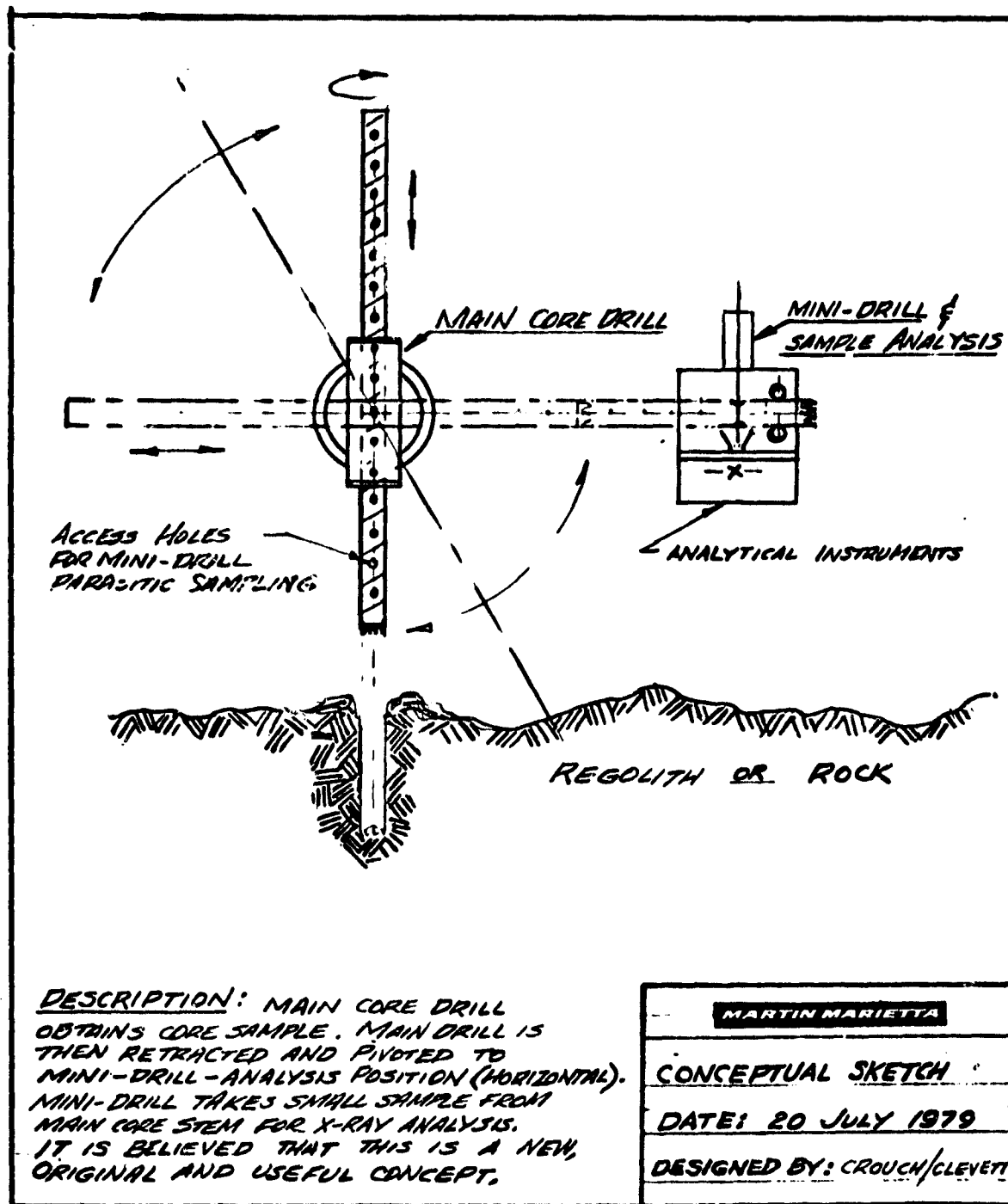


Figure C-2 Sketch - Parasitic Mini-Drill

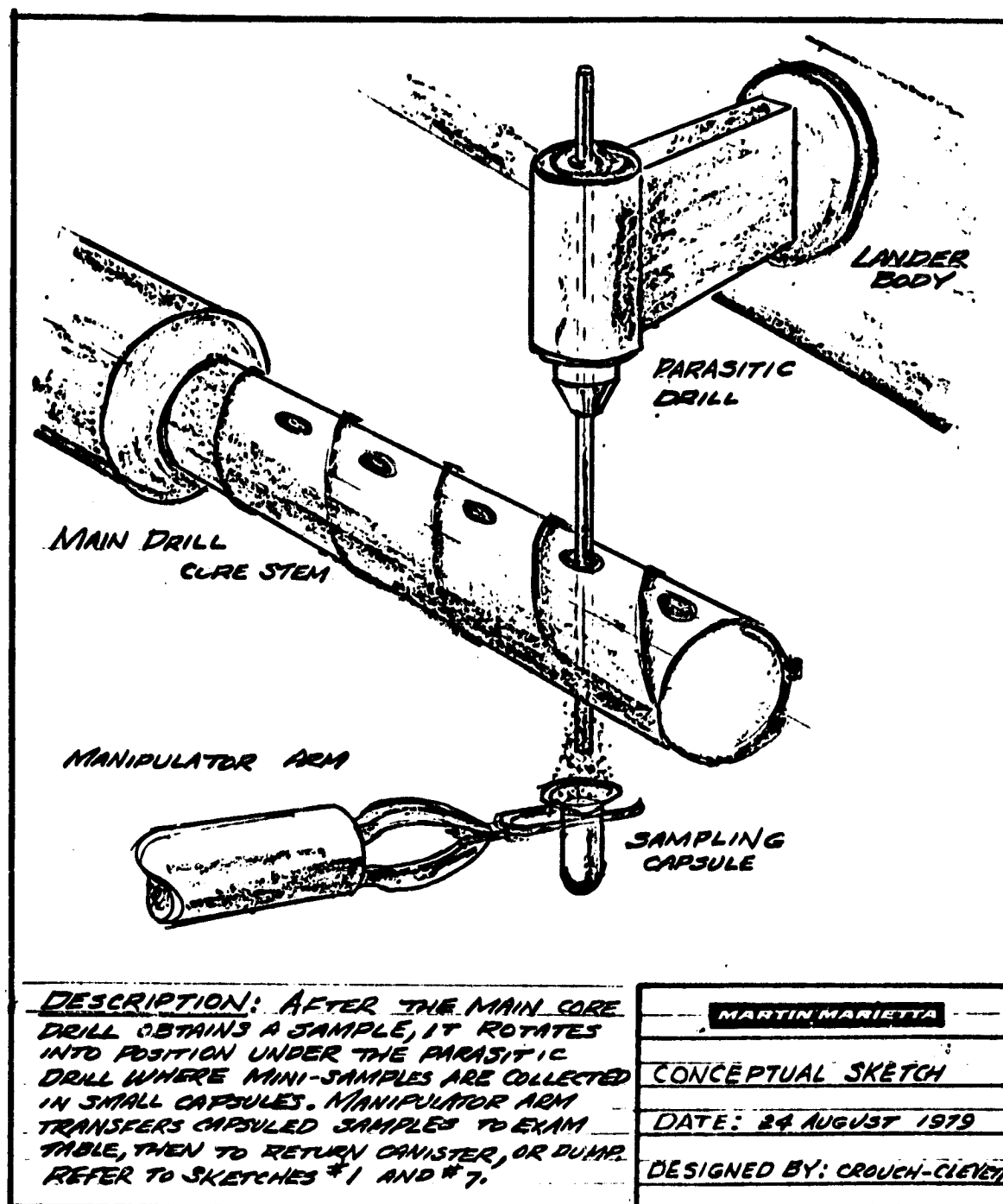


Figure C-3 Sketch - Parasitic Drill Sampling from Main Drill

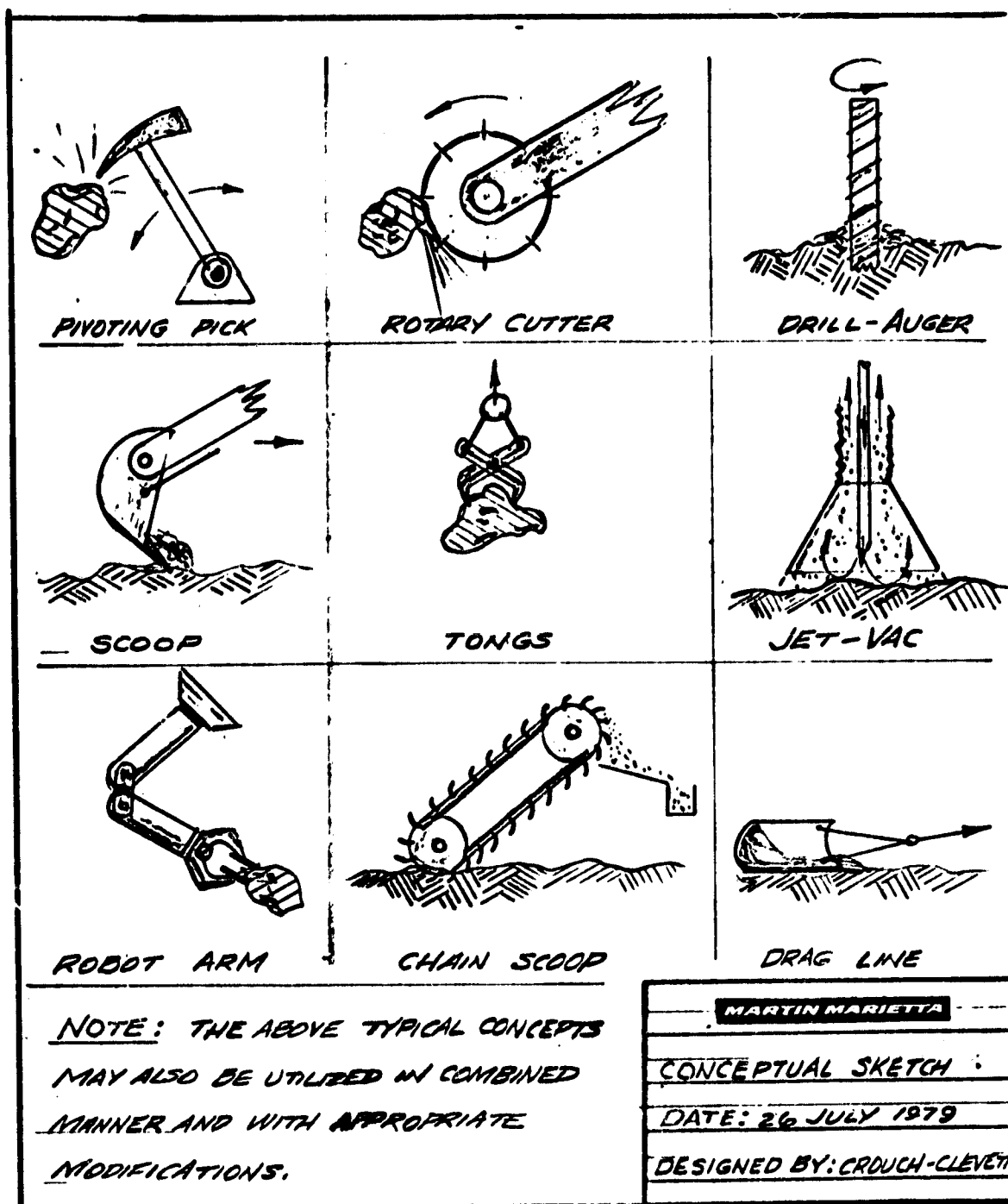


Figure C-4 Sketch - Candidate Mars Sampling Devices

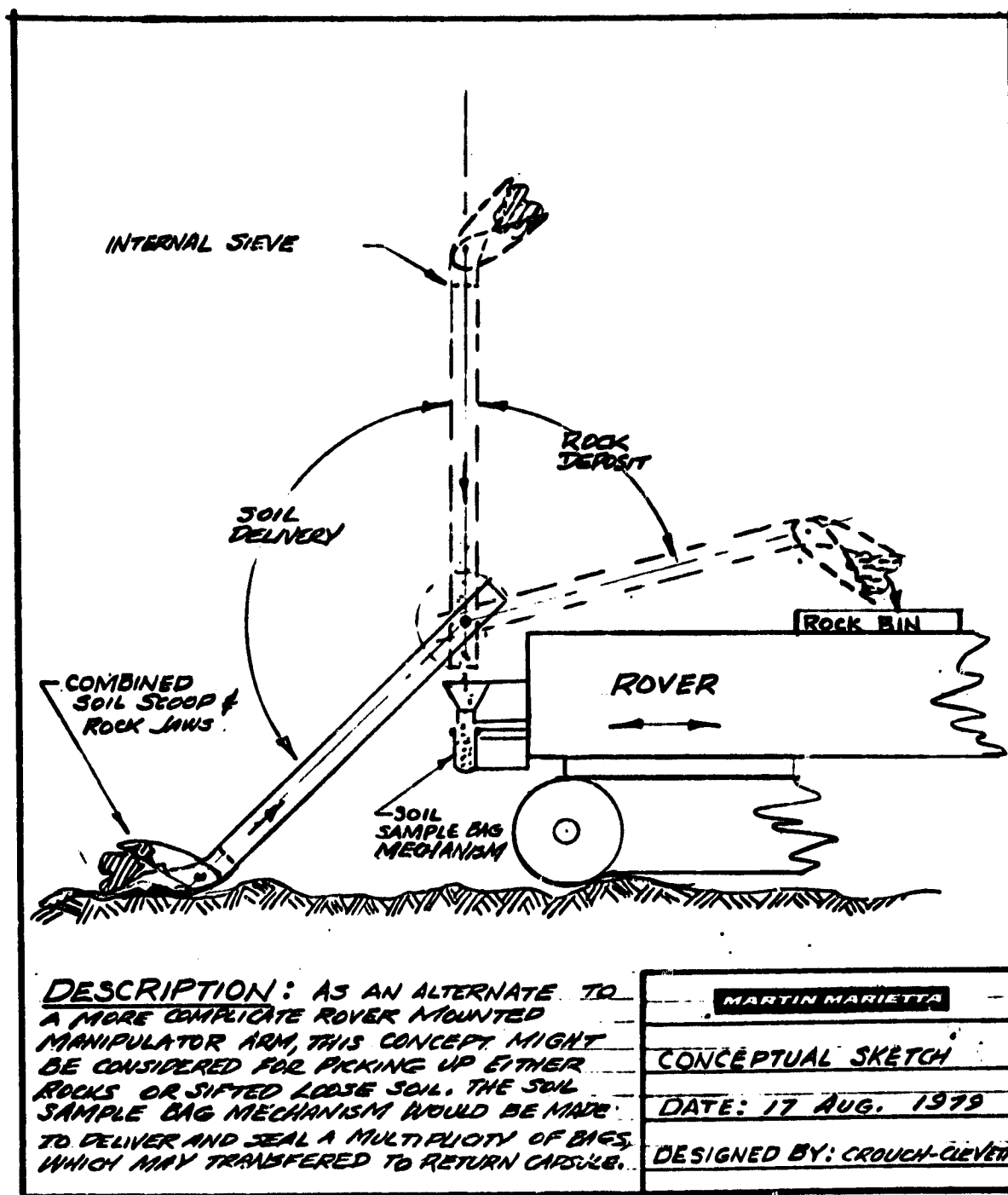


Figure C-5 Sketch - Rover-Mounted Sampling Scoop

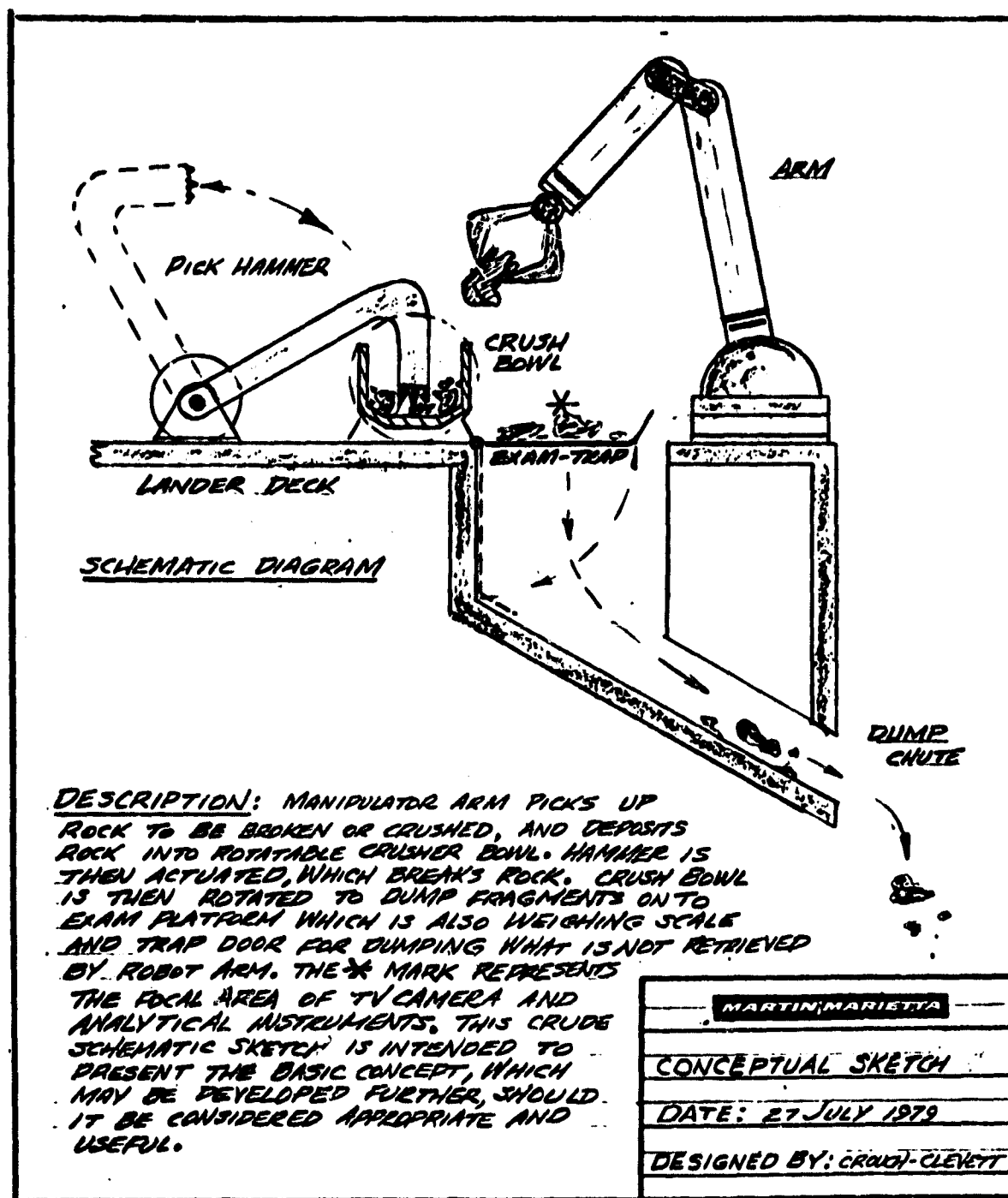


Figure C-6 Sketch - Lander-Mounted Rock Crusher

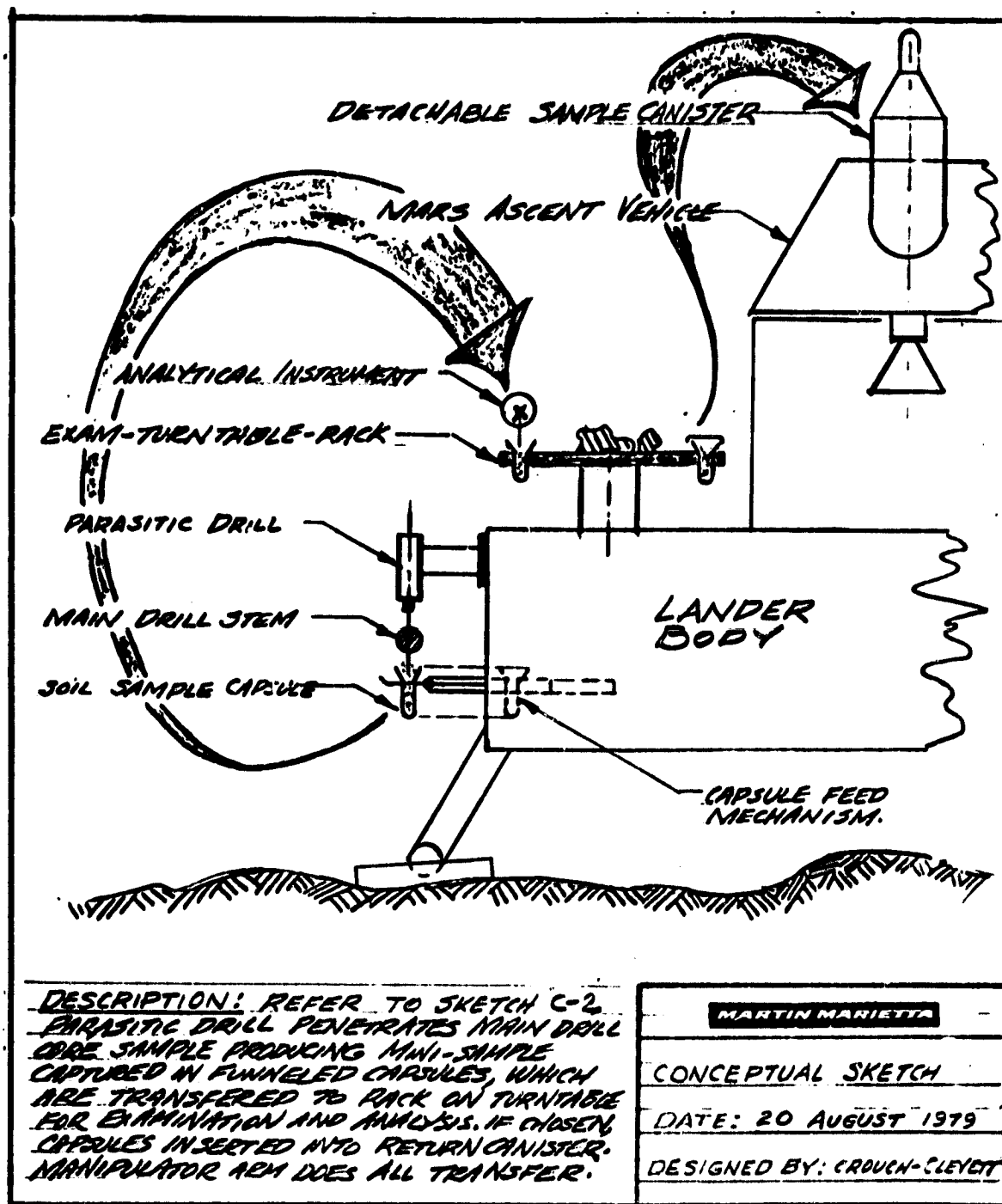


Figure C-7 Sketch - Lander-Mounted Sample Examination Turntable

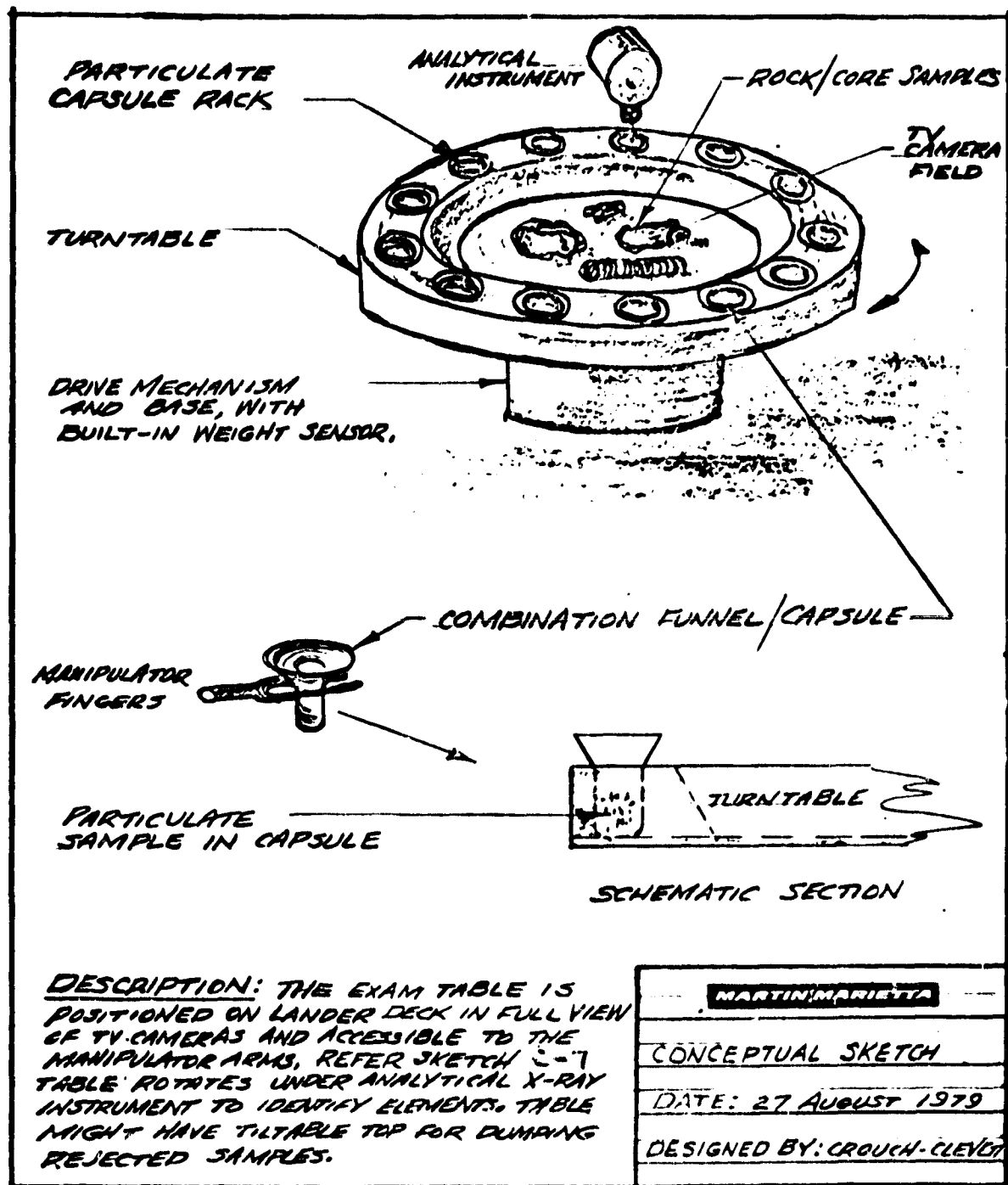


Figure C-8 Sketch - Lander-Mounted Sample Analysis Equipment

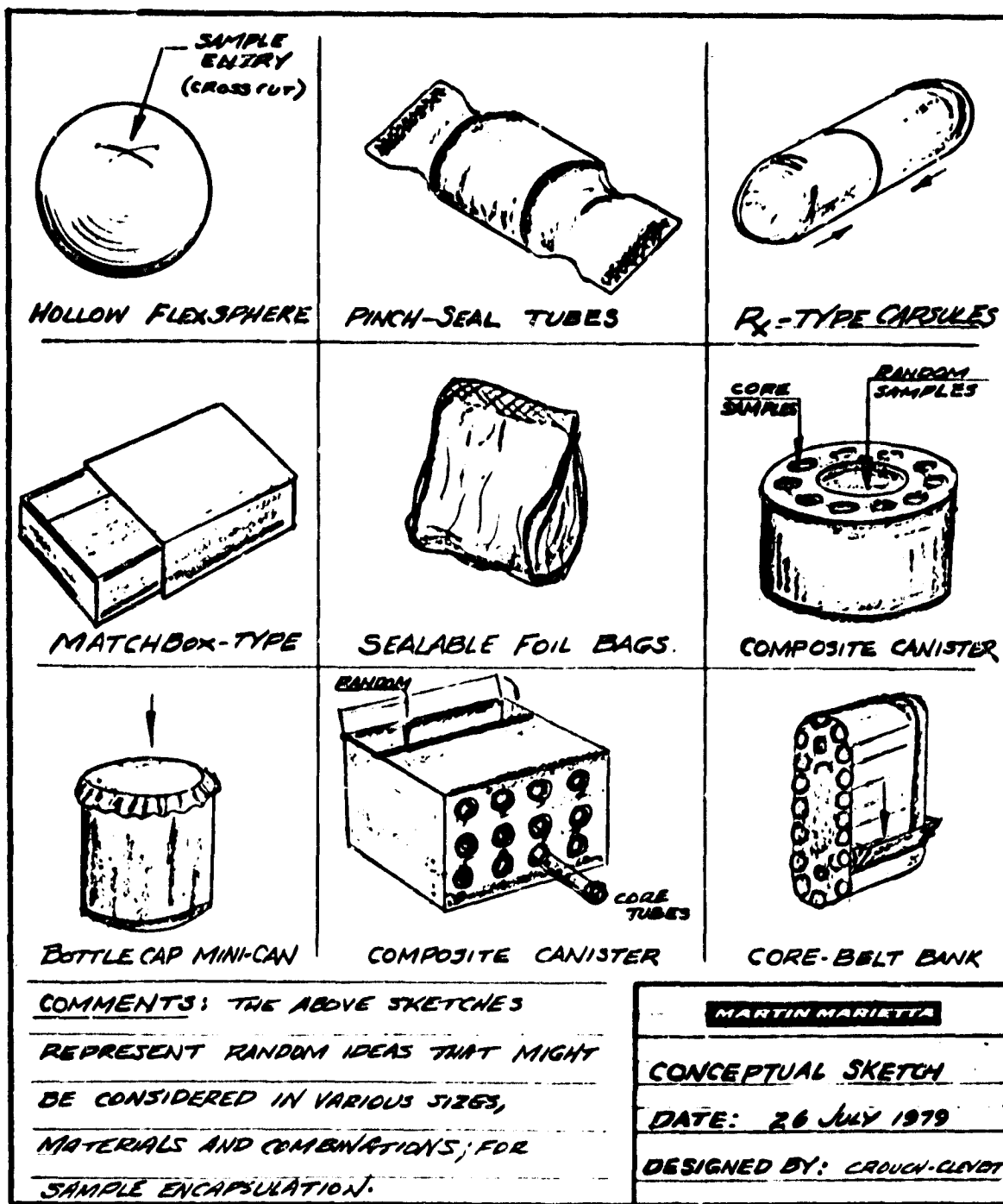


Figure C-9 Sketch - Candidate Sample Containers

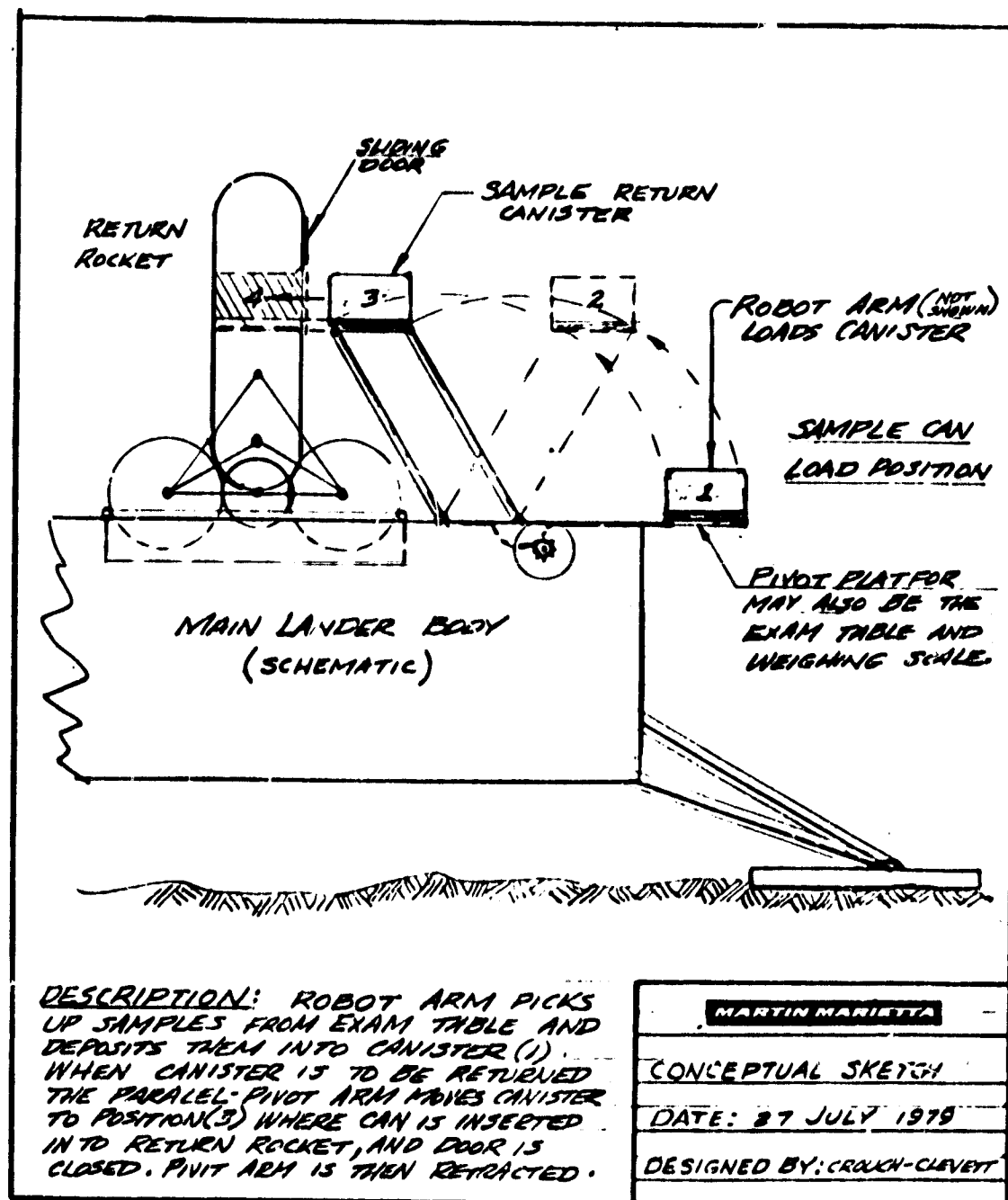


Figure C-10 Sketch - Sample Transfer to Earth Return Capsule

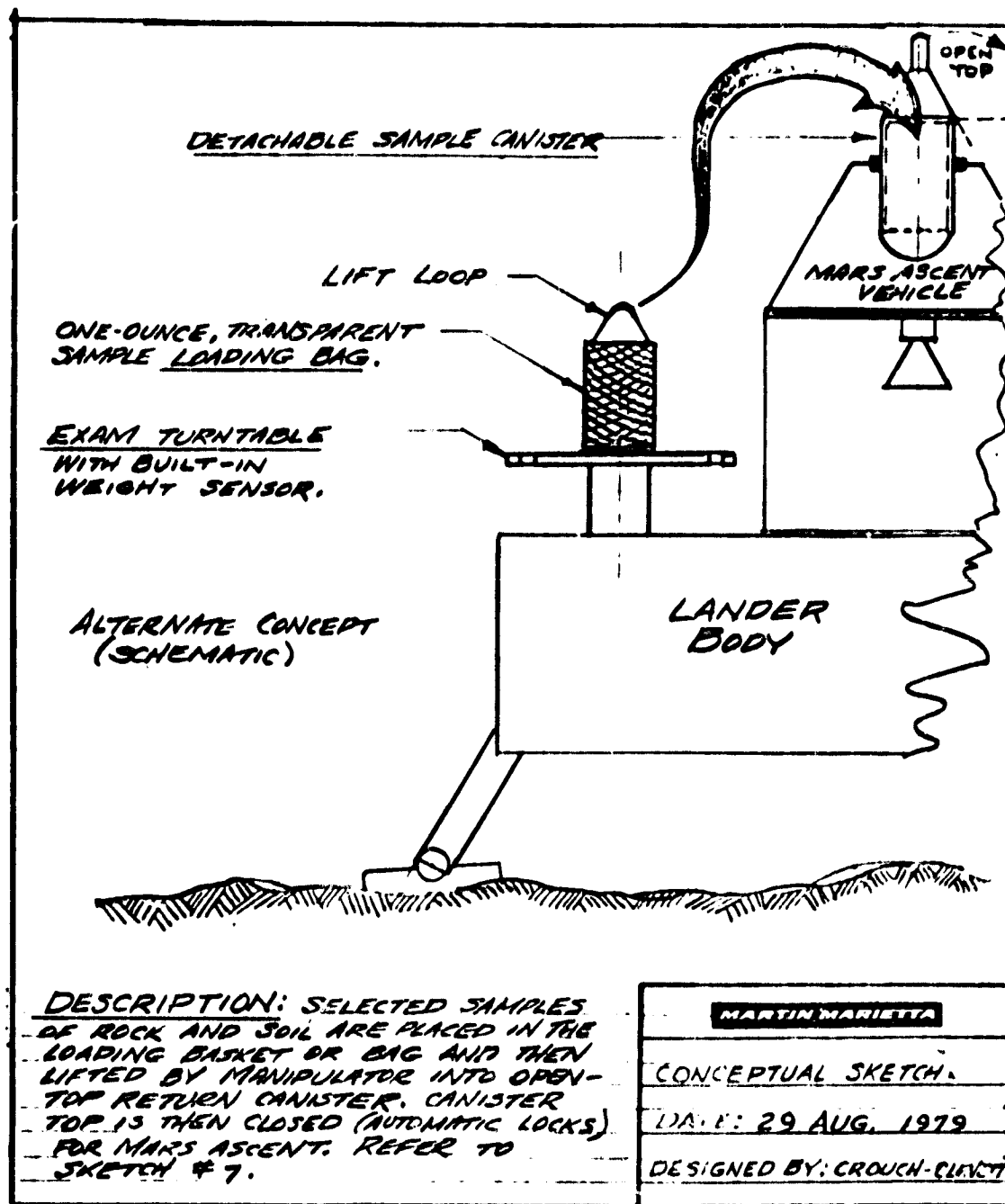


Figure C-11 Sketch - Alternate Sample Transfer Technique



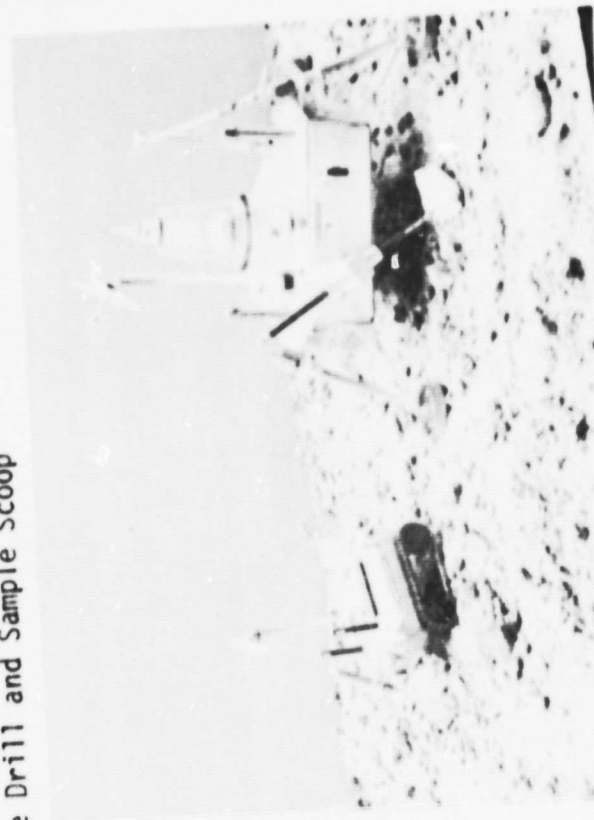
b. SCOOP DEPOSITING REGOLITH SAMPLES



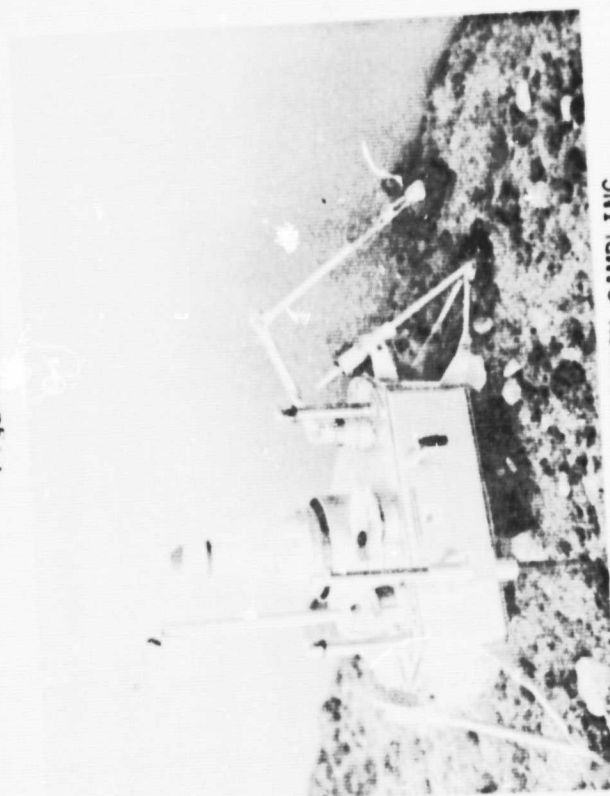
a) SCOOP DEPOSITING ROCK SAMPLES

Figure C-12 Model-Rover-Mounted Core Drill and Sample Scoop

C-13



b) LANDER AND ROVER SAMPLING



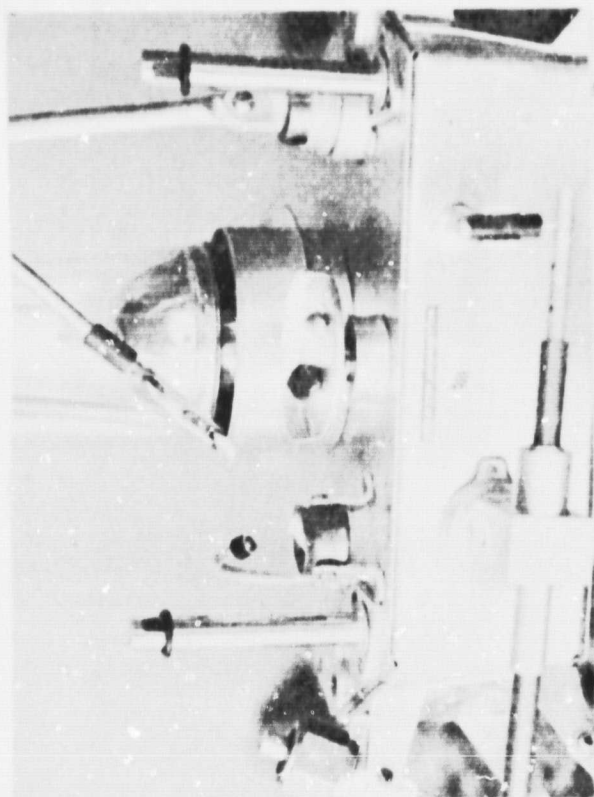
a) LANDER CONTINGENCY SAMPLING

Figure C-13 Model-Lander and Rover Core Drills and Robotic Arms

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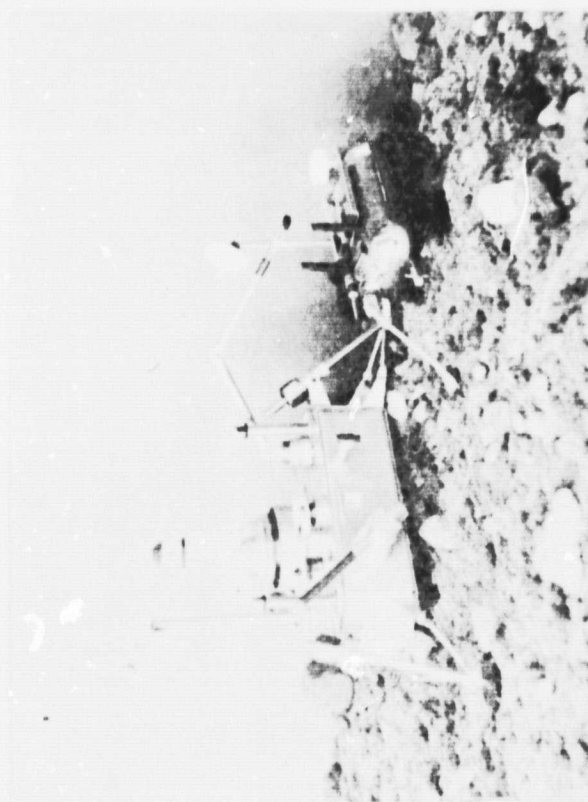
a) TRANSFER OF ROCKS FROM ROVER



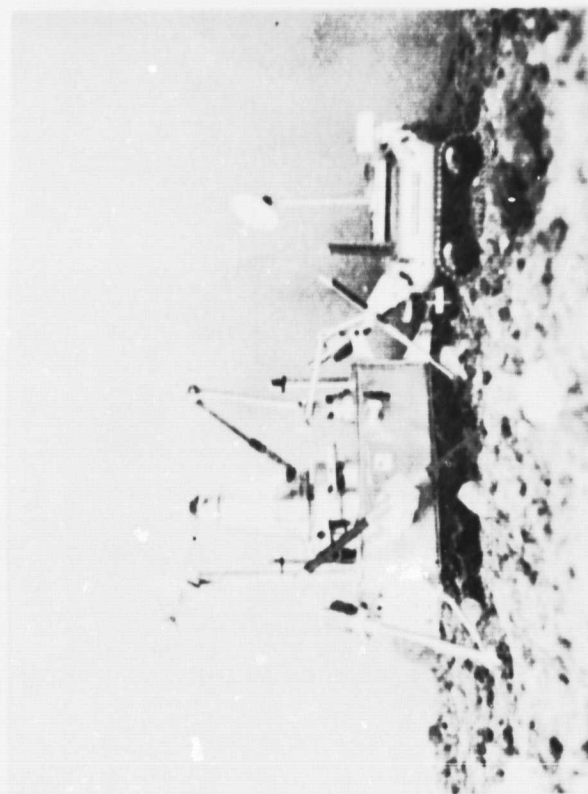
b) TRANSFER OF ROCKS TO CRUSHER AND EXAM TABLE

Figure C-14 Model-Sample Handling

C-14

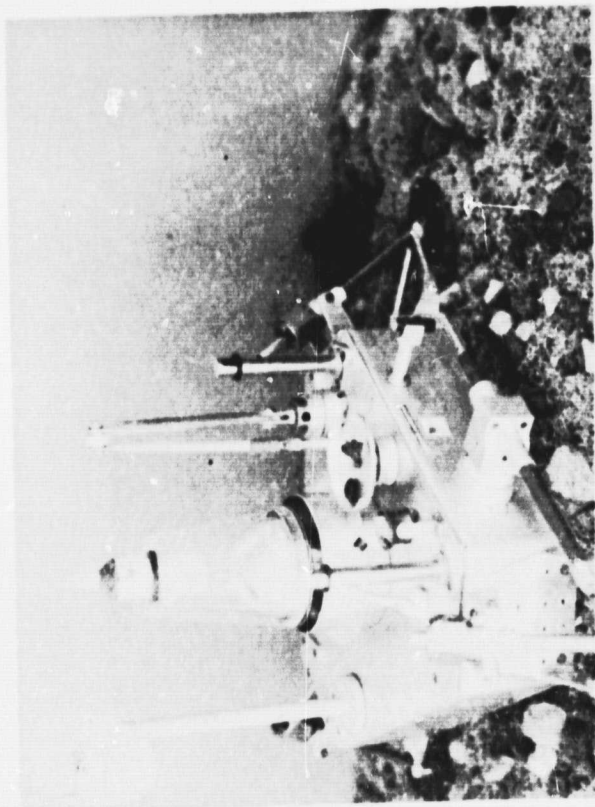


a) TRANSFER VIA LANDER ROBOTIC ARM

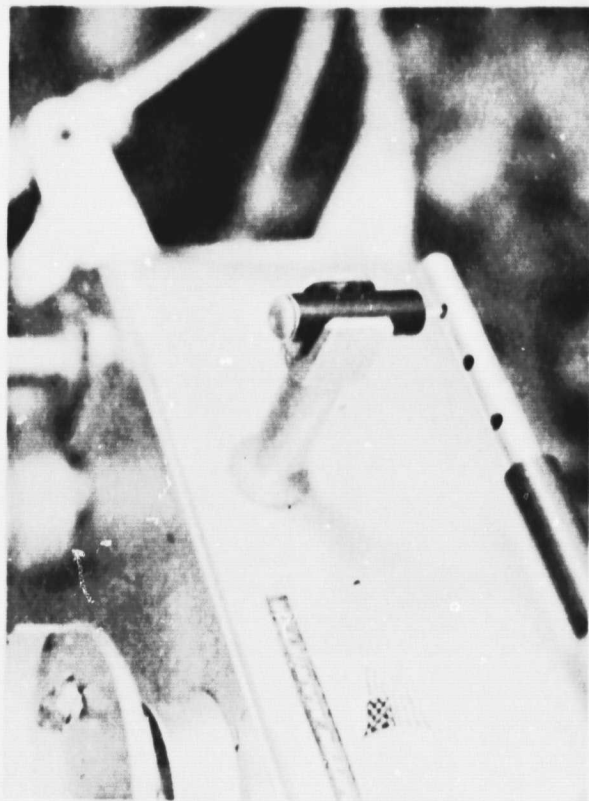


b) TRANSFER VIA ROVER ROBOTIC ARM

Figure C-15 Model-Rover-To-Lander Sample Transfer

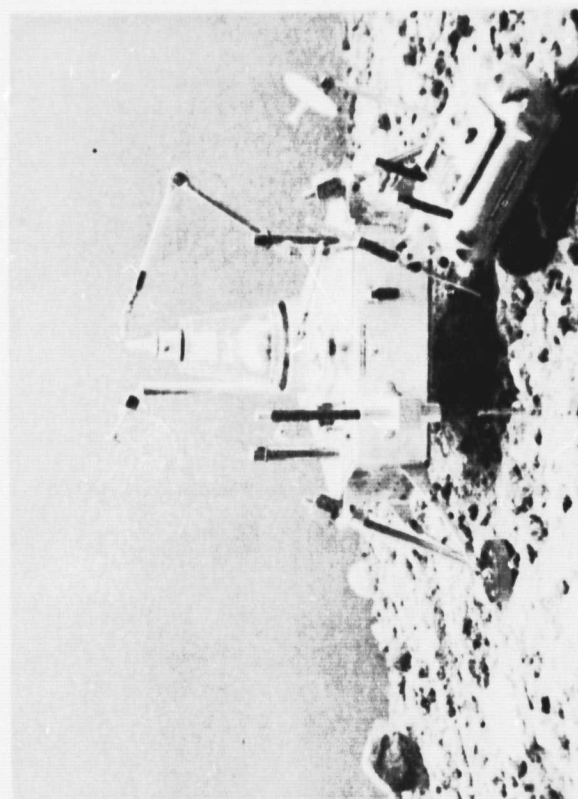


a) MAIN DRILL ROTATED 90°

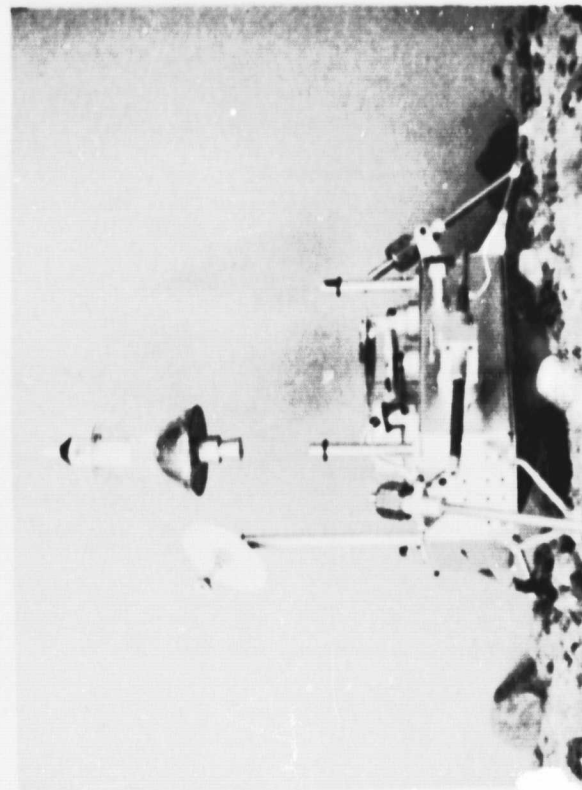


b) INTERMITTENT SAMPLES VIA MINI-DRILL

Figure C-16 Model-Parasitic Drill Operation



a) SAMPLE CONTAINER TO MARS ASCENT VEHICLE



b) MARS ASCENT VEHICLE LIFT-OFF

Figure C-17 Model-Sample Transfer

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APPENDIX D
CONCEPTUAL DESIGN DRAWINGS

The following design drawings are contained in this appendix:

DRAWING NUMBER	PAGE	TITLE	SCALE OF ORIGINAL
MSR-100000	D-2	Rover Core Drill Collection System-General Arrangement	One-Quarter
MSR-100100	D-3	Core Drill Positioning System (CDPS)	Full
MSR-110000	D-4	Core Drill Collection System (CDCS)	One-Half
MSR-110100	D-5	Regolith and Rock Core Drills	Full
MSR-120000	D-6	Rock Core Handling System (RCHS)	Full
MSR-120100	D-7	Rock Core Sample Container and Release Mechanism	Full
MSR-120200	D-8	Rock Core Drill Exchange Mechanism	Full
MSR-130000	D-9	Regolith Sample Handling System (RSHS)	Full
MSR-130100	D-10	Regolith Sample Collection Tube Procedure	Full
MSR-200000	D-11	Lander Mounted Rock Breaker System	Full
MSR-300000	D-12	Rover Surface Sample Collection System General Arrangement	Full
MSR-310000	D-13	Sample Collection Hand	Full
MSR-320000	D-14	Regolith Sample Storage	Full

NOTE: Original drawings on file at Martin Marietta
Full-size copies of drawings available from
Dr. U. S. Clanton, NASA/JSC

REMOTE MANIPULATOR SYSTEM (RMS)

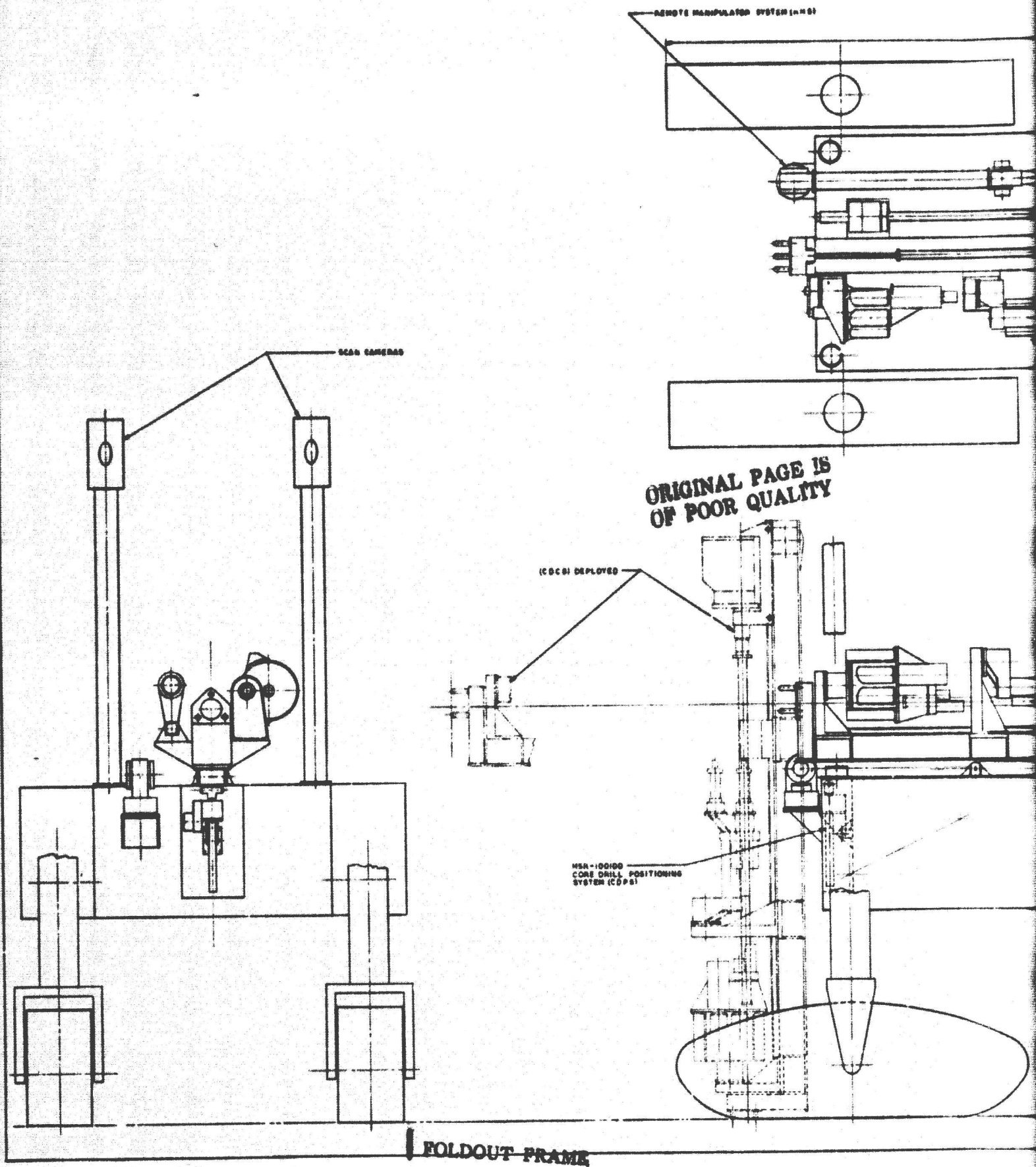
SCAN CAMERAS

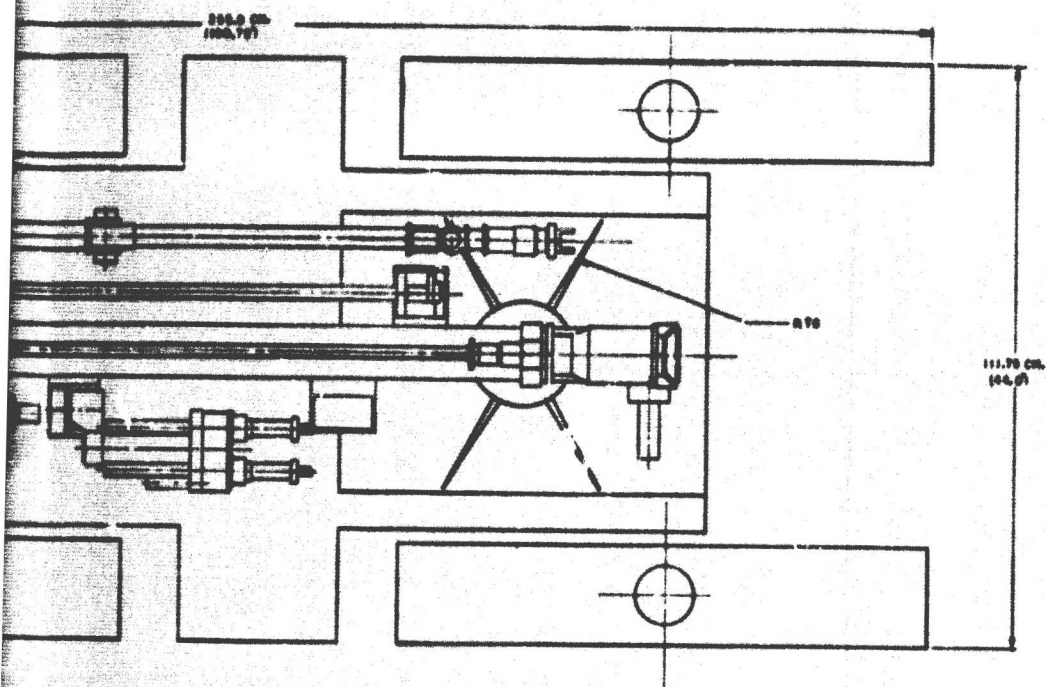
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(CDC) DEPLOYED

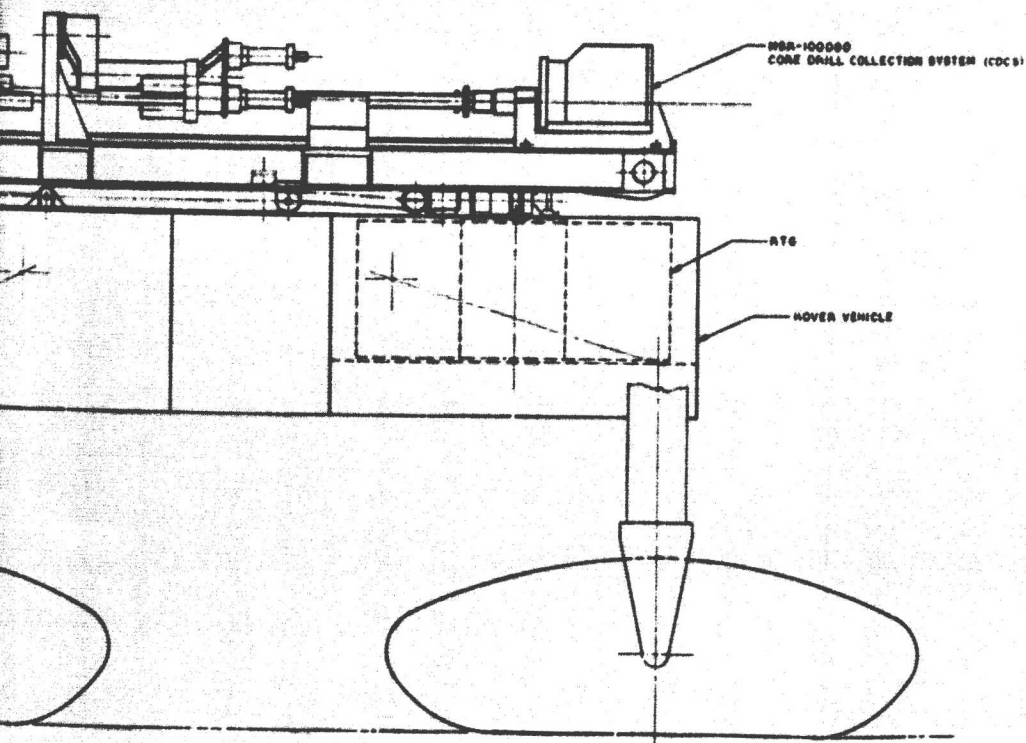
MSR-100100
CORE DRILL POSITIONING
SYSTEM (CDPS)

FOLDOUT FRAME





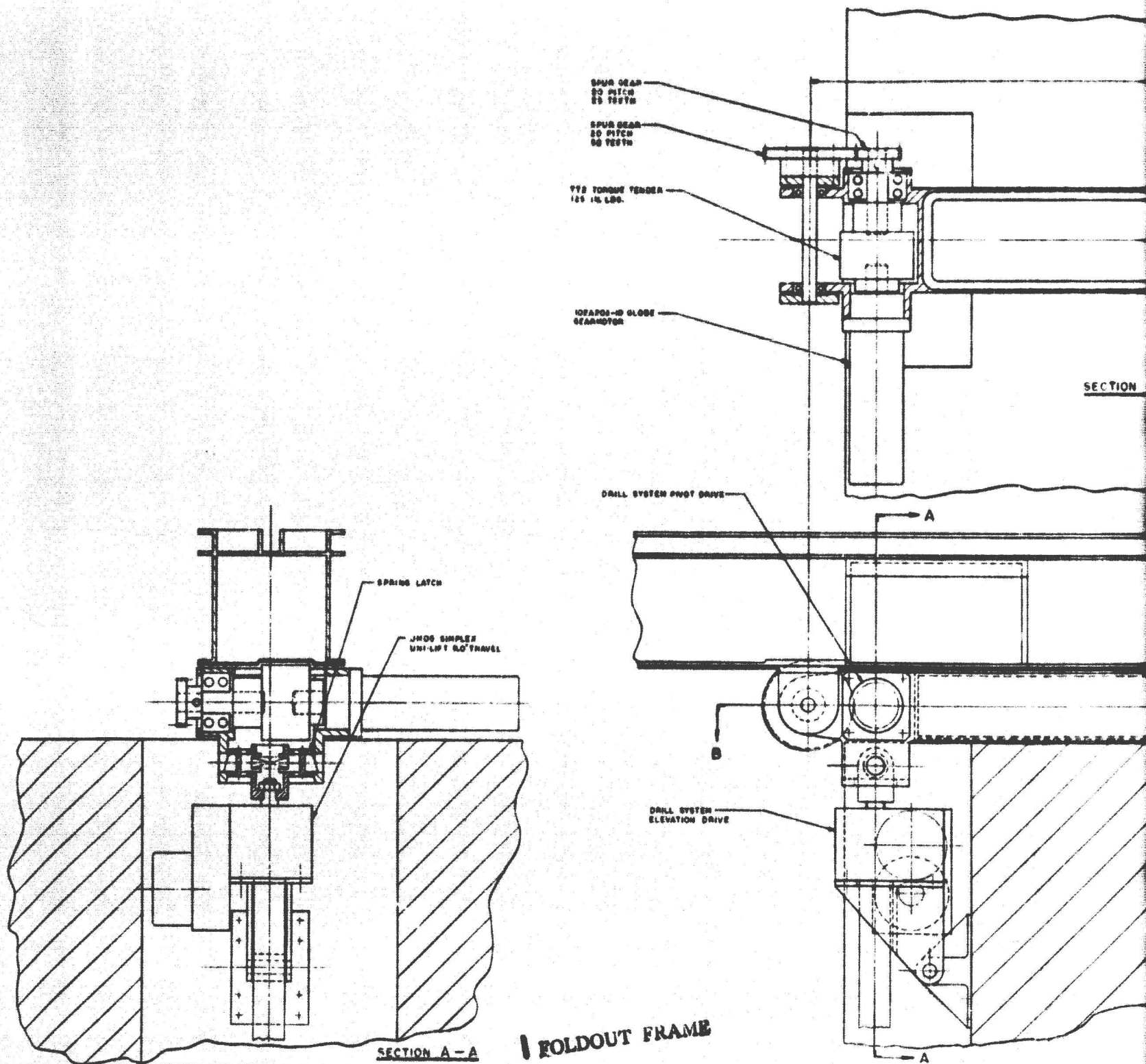
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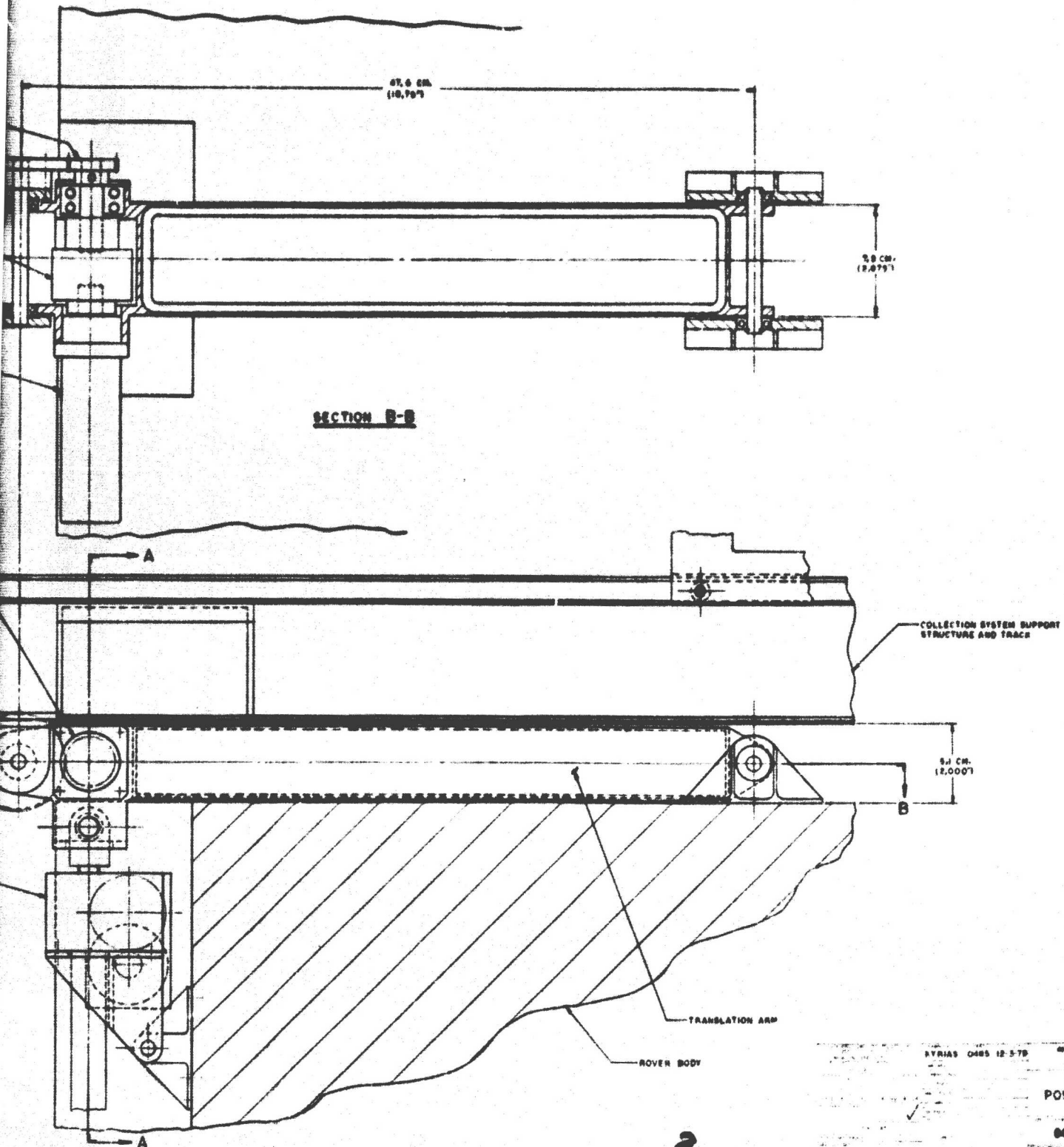
HYDRA 0465 12-5-79	DESIGN ENGINEER APPROVED
	DATE 12-5-79
ROVER CORE DRILL COLLECTION SYSTEM - GENERAL ARRANGEMENT	
04655	MSR-100000
1/3	1 OF 1

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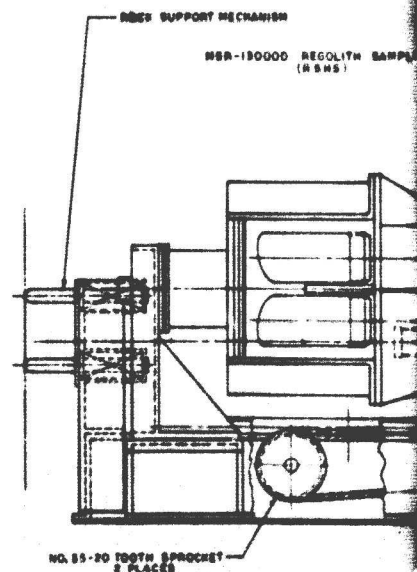
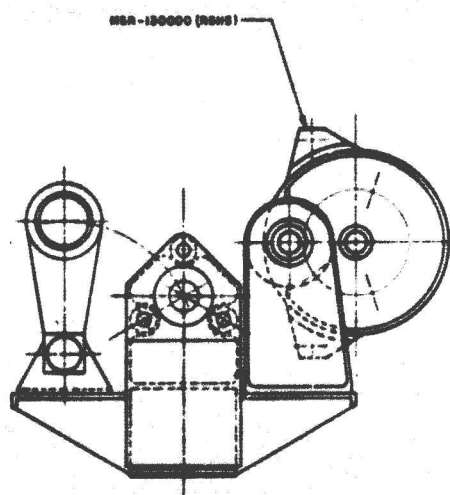
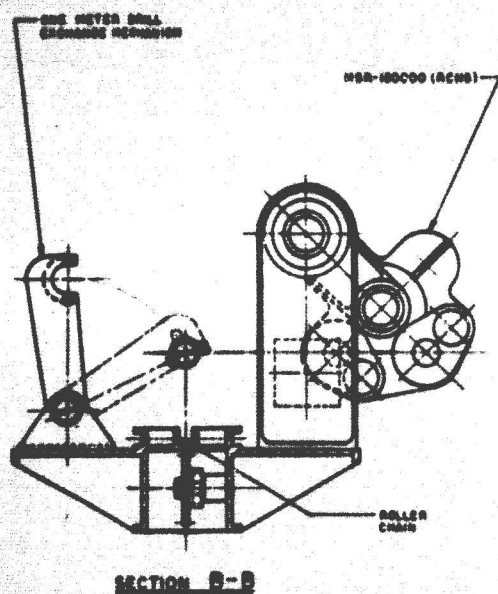
SYNOPSIS 0485 12-5-79

0485 12-5-79

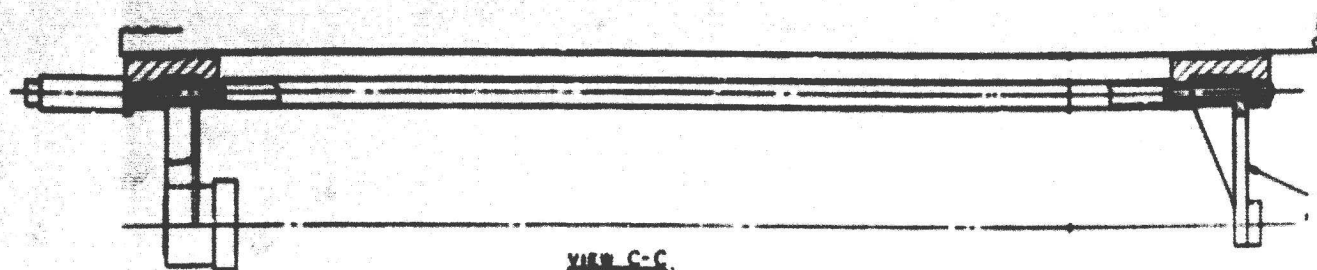
CORE DRILL
POSITIONING SYSTEM
(COPS)

0485 MSR 100100

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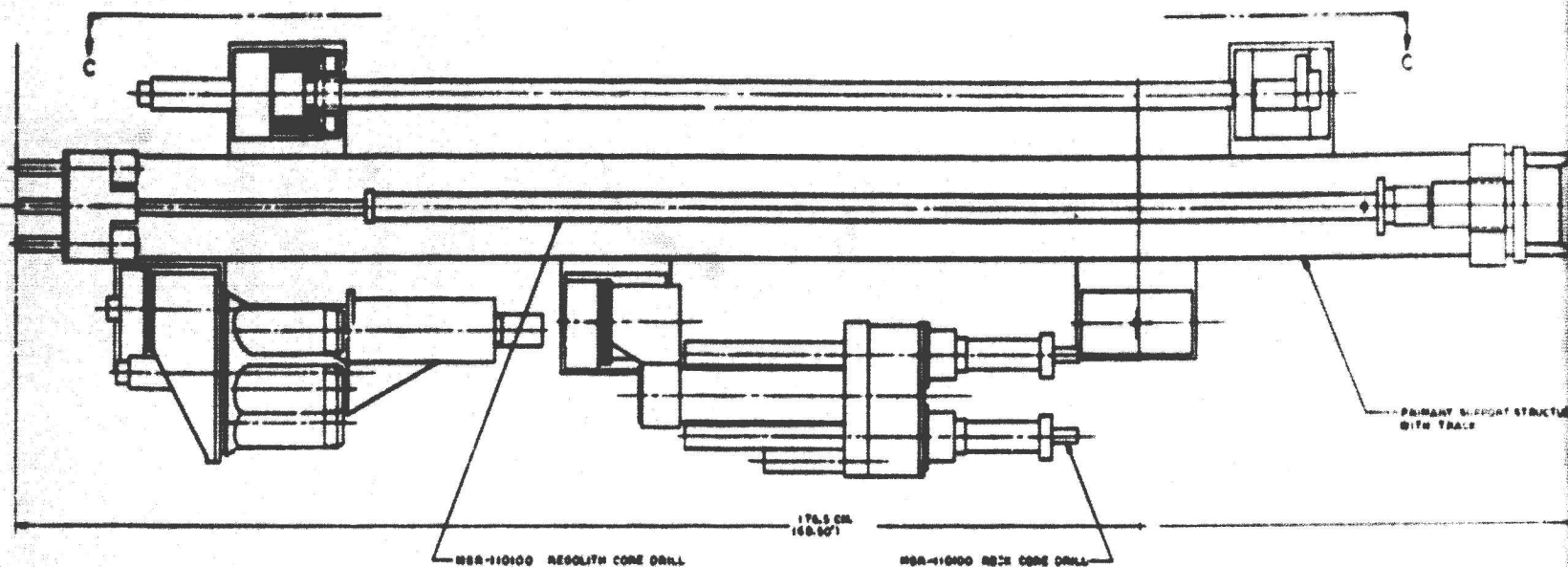


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ONE MOTOR
EXCHANGE MECHANISM

VIEW C-C



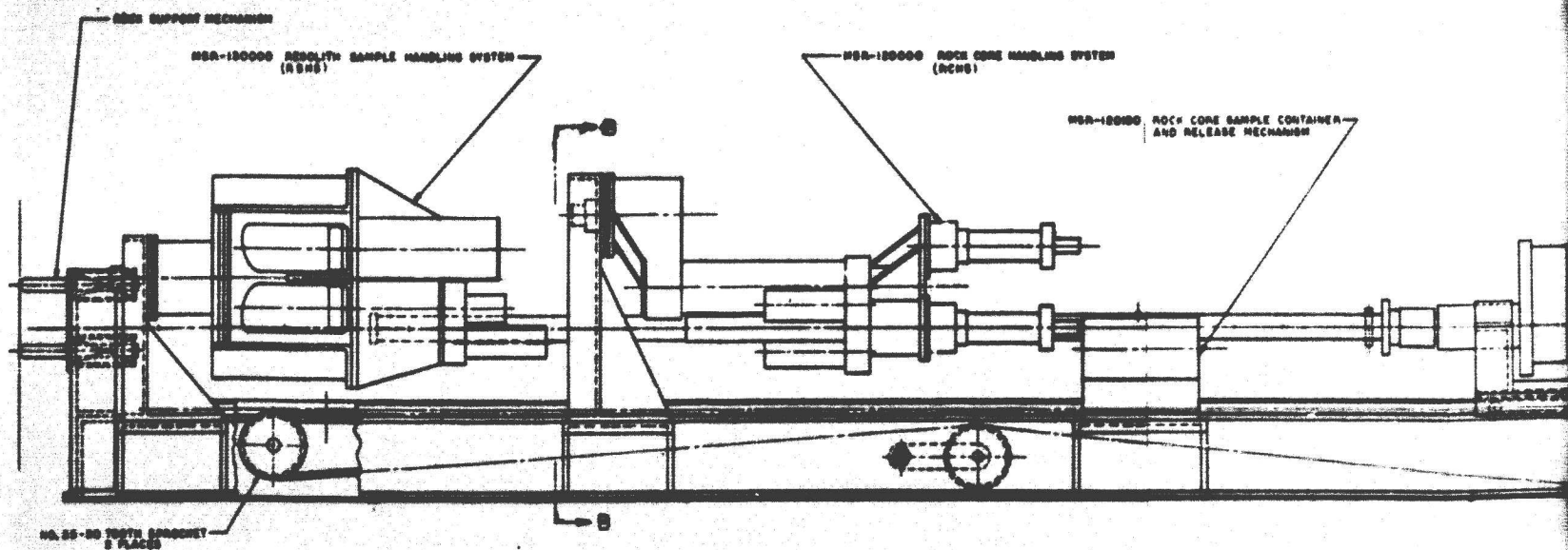
PRIMARY SUPPORT STRUCTURE
WITH TRACK

MSR-110100 RESOLITH CORE DRILL

176.5 CM
(69.50')

MSR-110100 ROCK CORE DRILL

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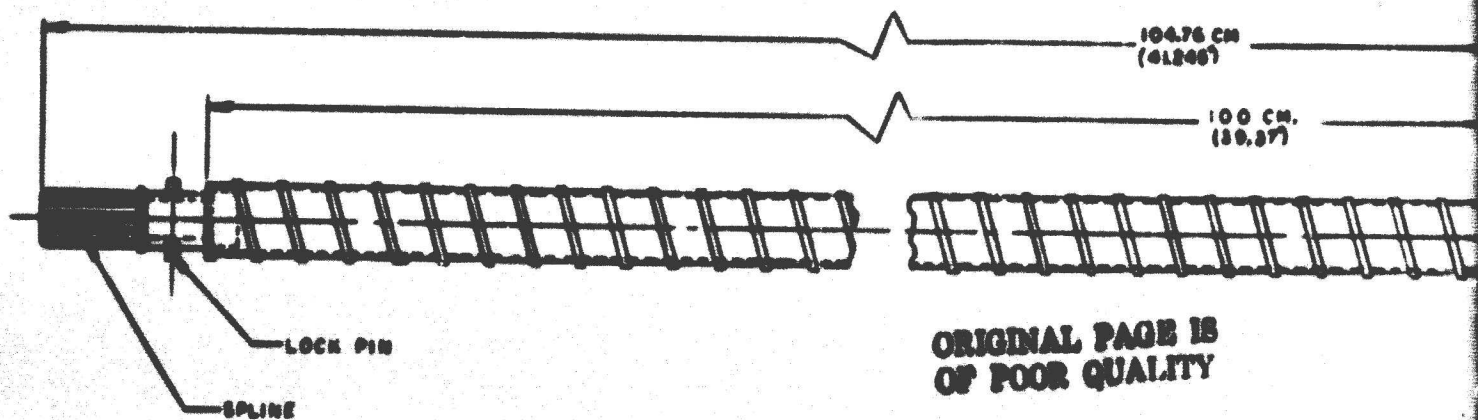
ROCK SUPPORT MECHANISM

MSR-120000 RESOLITH SAMPLE HANDLING SYSTEM
(RSHS)

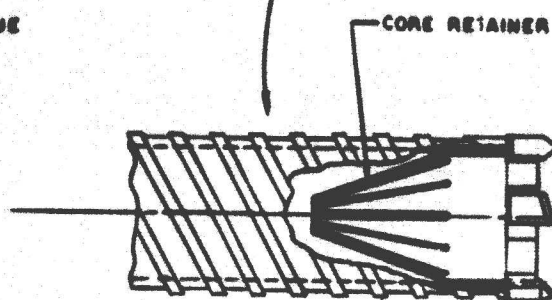
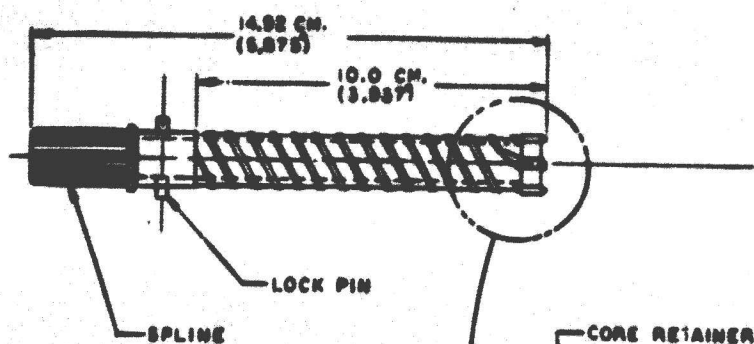
MSR-120000 ROCK CORE HANDLING SYSTEM
(RCHS)

MSR-120000 ROCK CORE SAMPLE CONTAINER
AND RELEASE MECHANISM

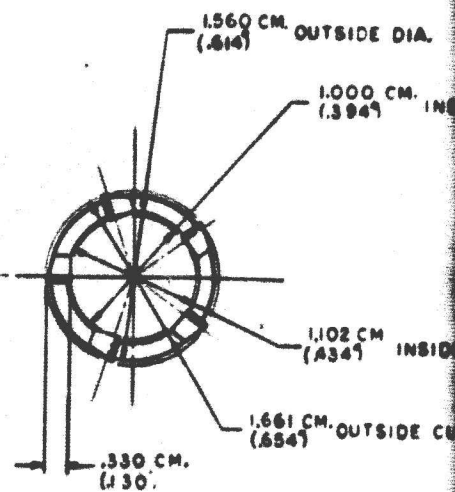
NO. 55-50 TIGHT BRACKET
2 PLACES



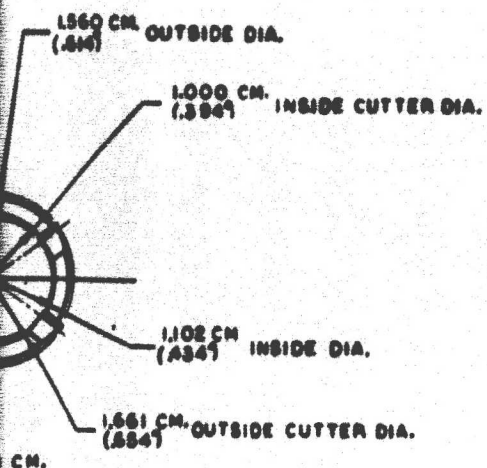
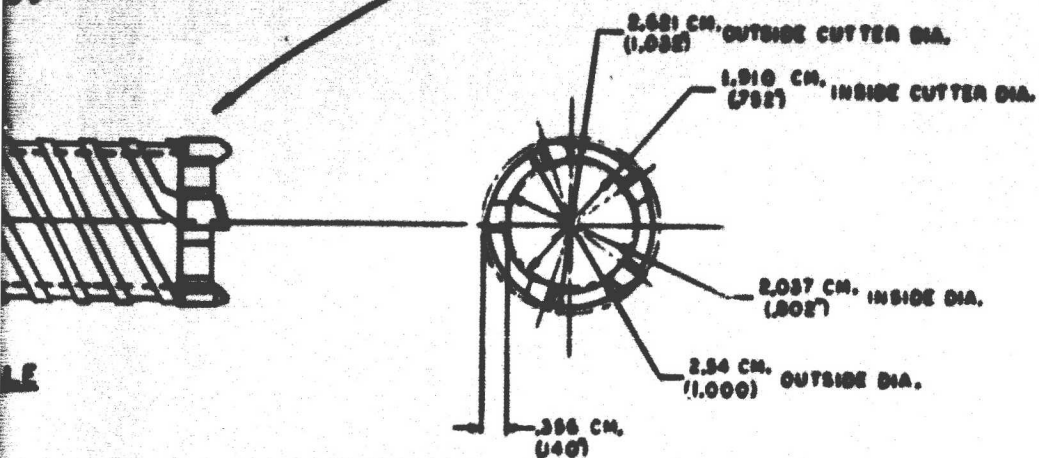
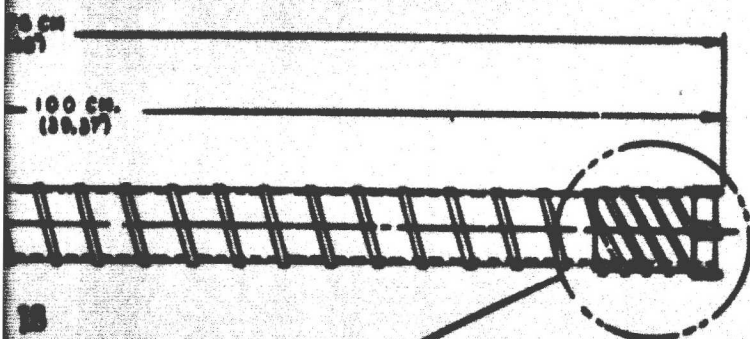
NO SCALE
REGOLITH CORE DRILL



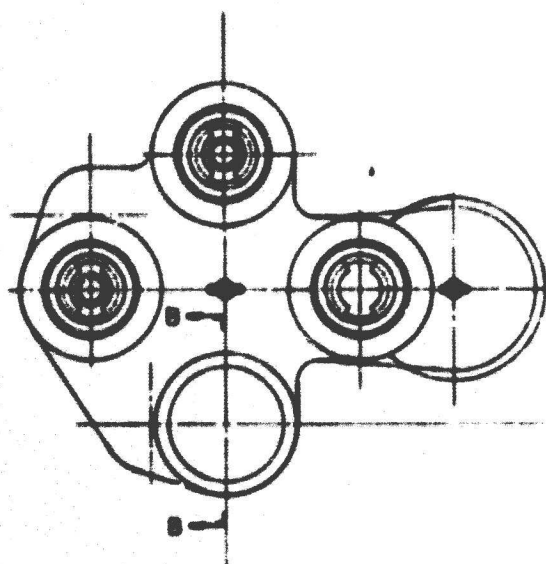
NO SCALE
ROCK CORE DRILL



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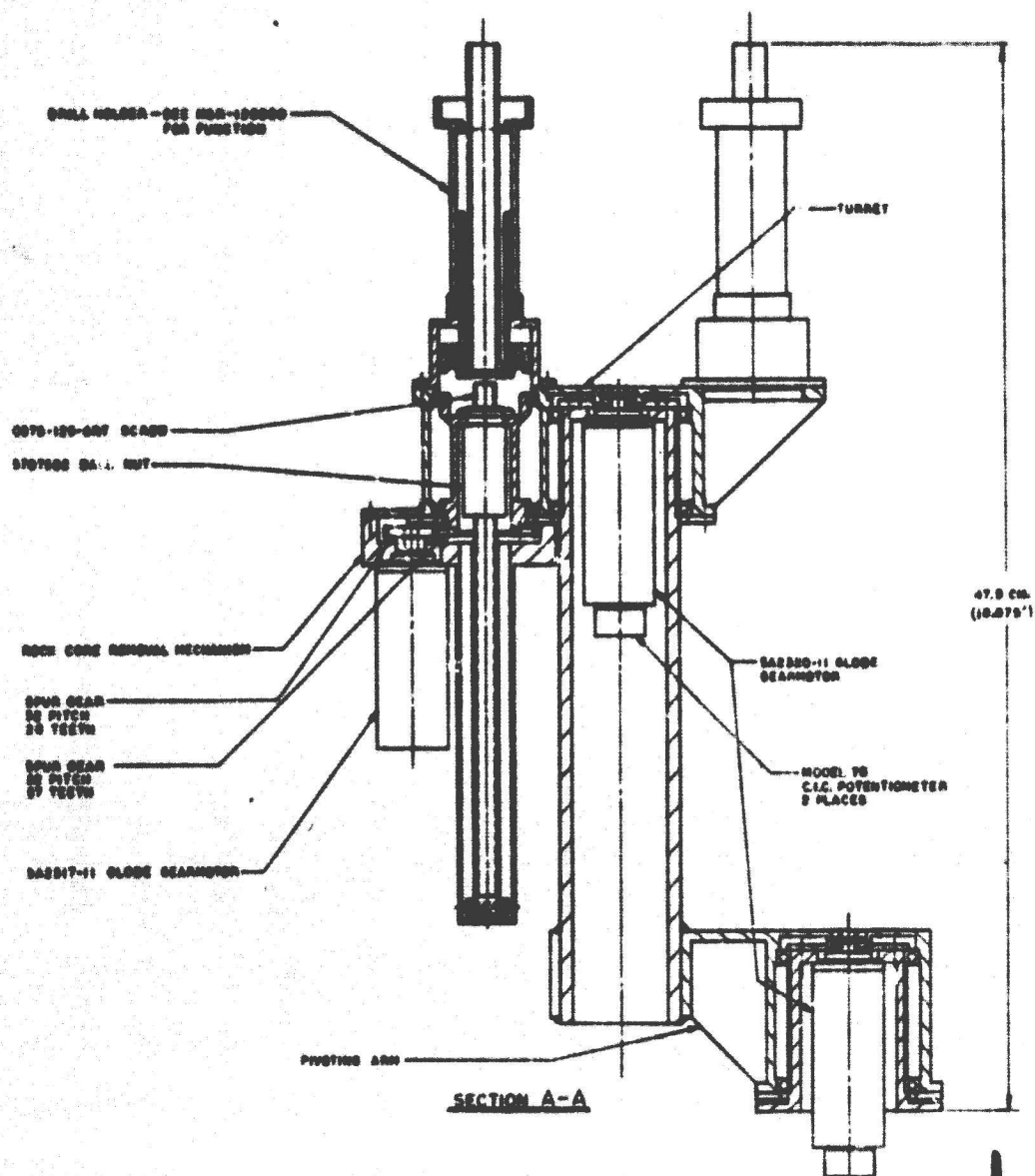


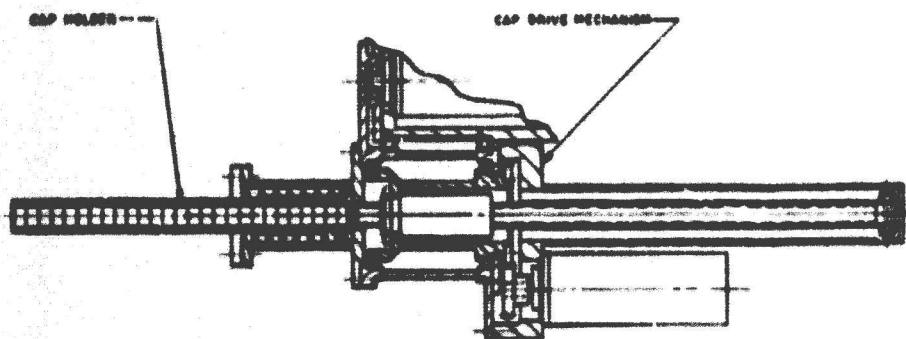
OLDOUT FRAME KYRIAS 0485 12-1-79		REGOLITH AND ROCK CORE DRILLS	
04850		MSR-110100	



CAP HOLE

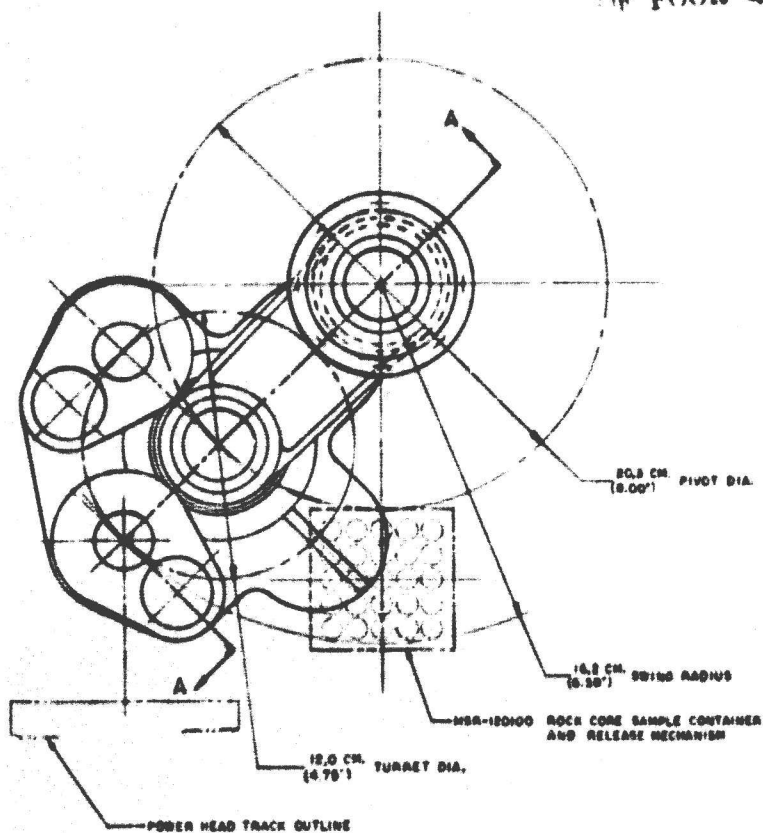
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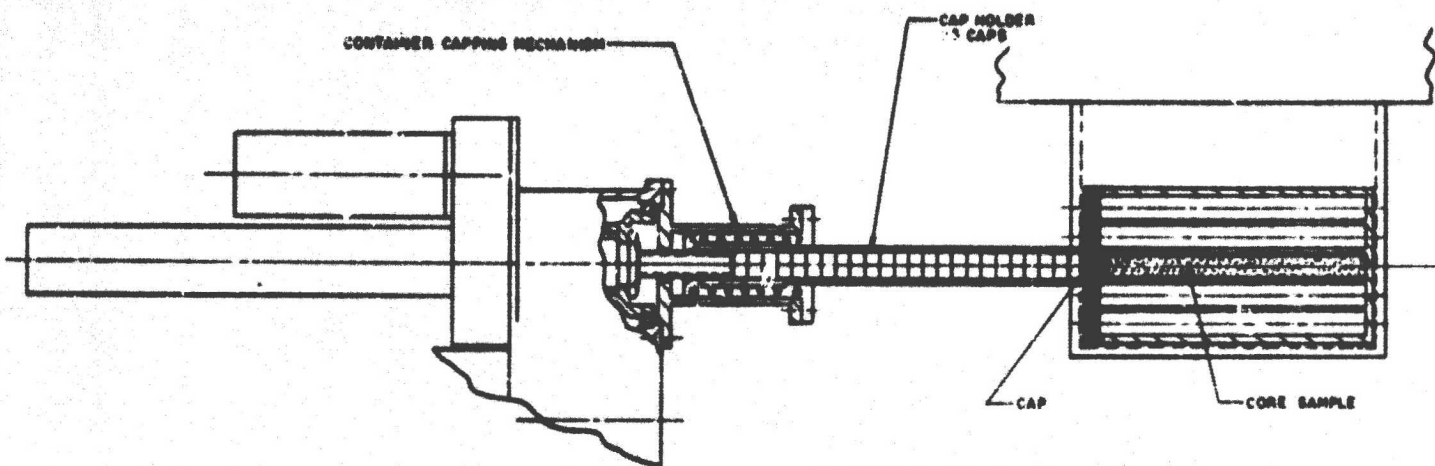
SECTION B-B
SEE MSR-12000 FOR FUNCTION

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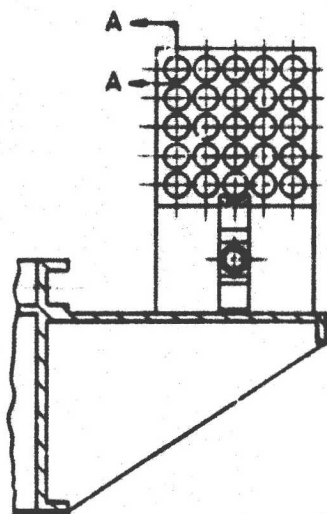
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DRAWING NO. 0488 12-2-75 DESIGNED BY J. J. J. CHECKED BY J. J. J. APPROVED BY J. J. J. DATE 12-2-75		ROCK CORE HANDLING SYSTEM (RCHS) 0488 MSR 120000	
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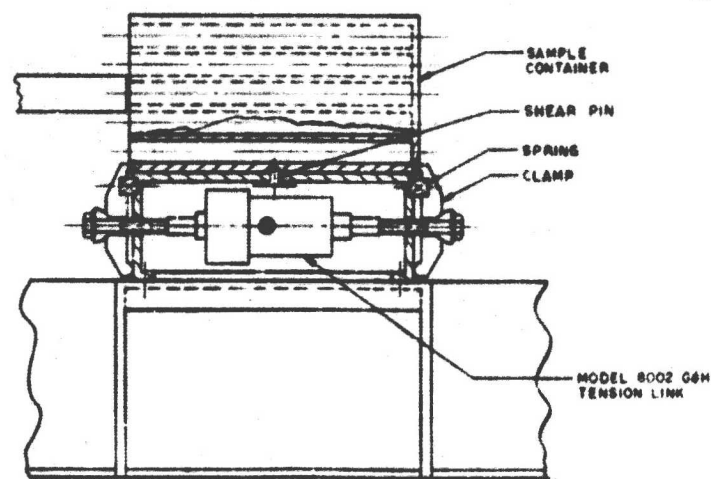


ROCK CORE SAMPLE CONTAINER

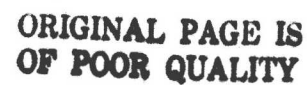
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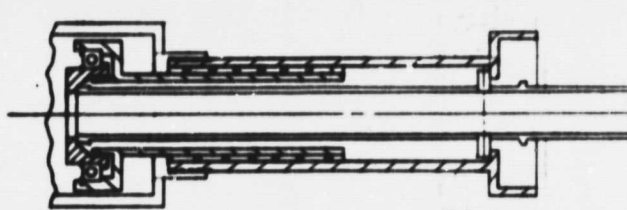


CONTAINER RELEASE MECHANISM

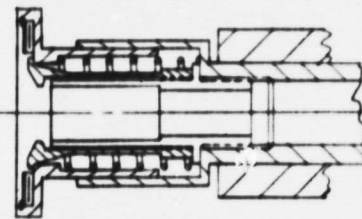


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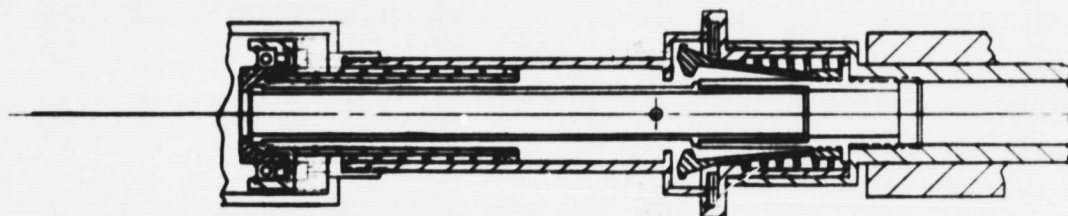
[illegible]



(6) POWER HEAD RETRACTED FROM SPLINE END OF DRILL.

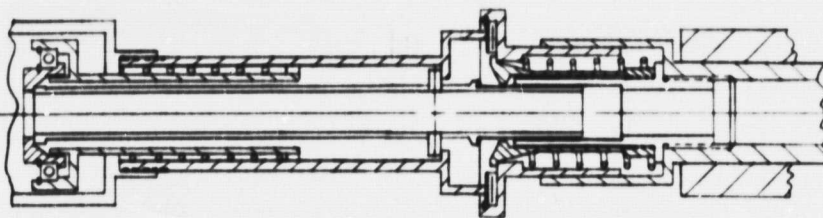


(5) POWER
IN

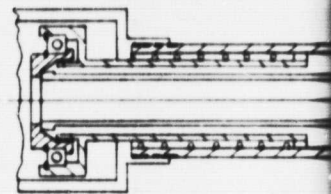


(3) COLLET AND HOLDER SPRINGS COMPRESSED
COLLET RELEASED

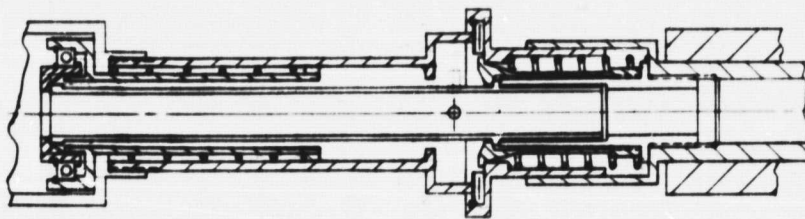
FOLDOUT FRAME



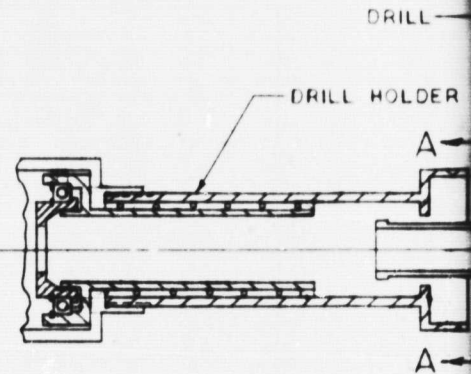
(5) POWER HEAD RETRACTED. RETAINER PIN
IN LOCK DETENT.



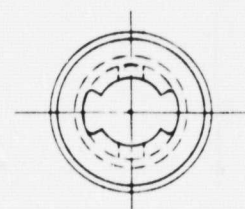
(4) POWER HEAD RE
RETAINER PIN



(2) INITIAL INSERTION OF DRILL INTO HOLDER

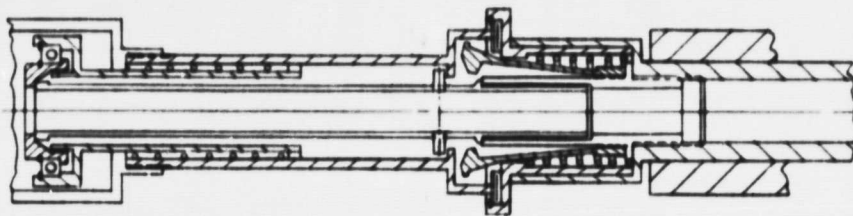


(1) DRILL ATTACH

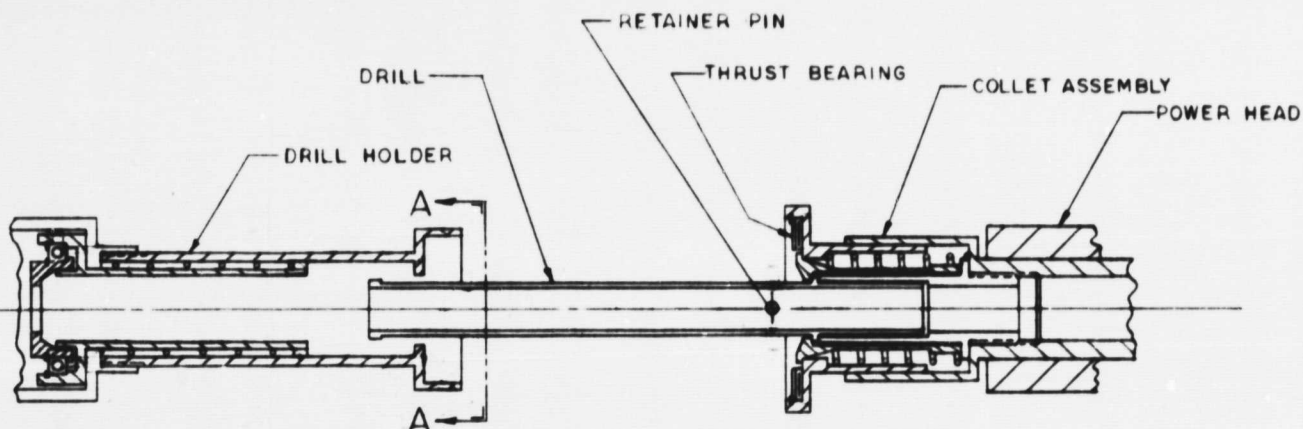


SECTION A-A

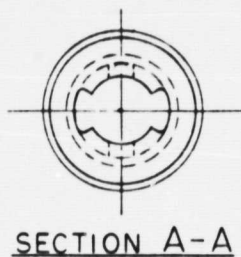
2 FOLDOUT FRAME



(4) POWER HEAD ROTATES DRILL 90°
RETAINER PIN IN LOCK POSITION.

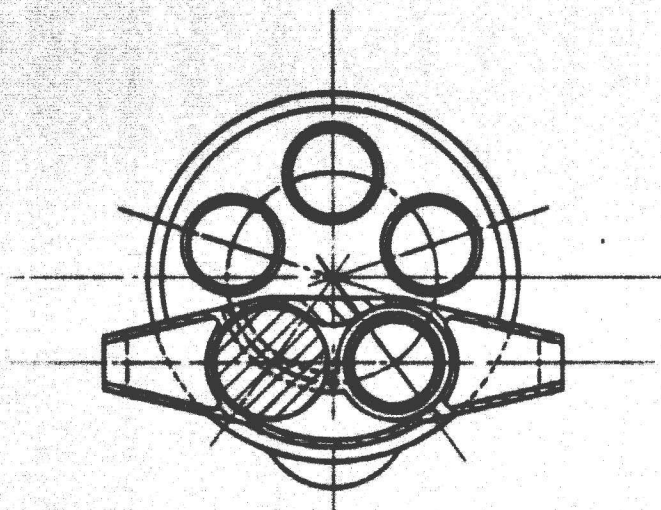


(1) DRILL ATTACHED TO POWER HEAD

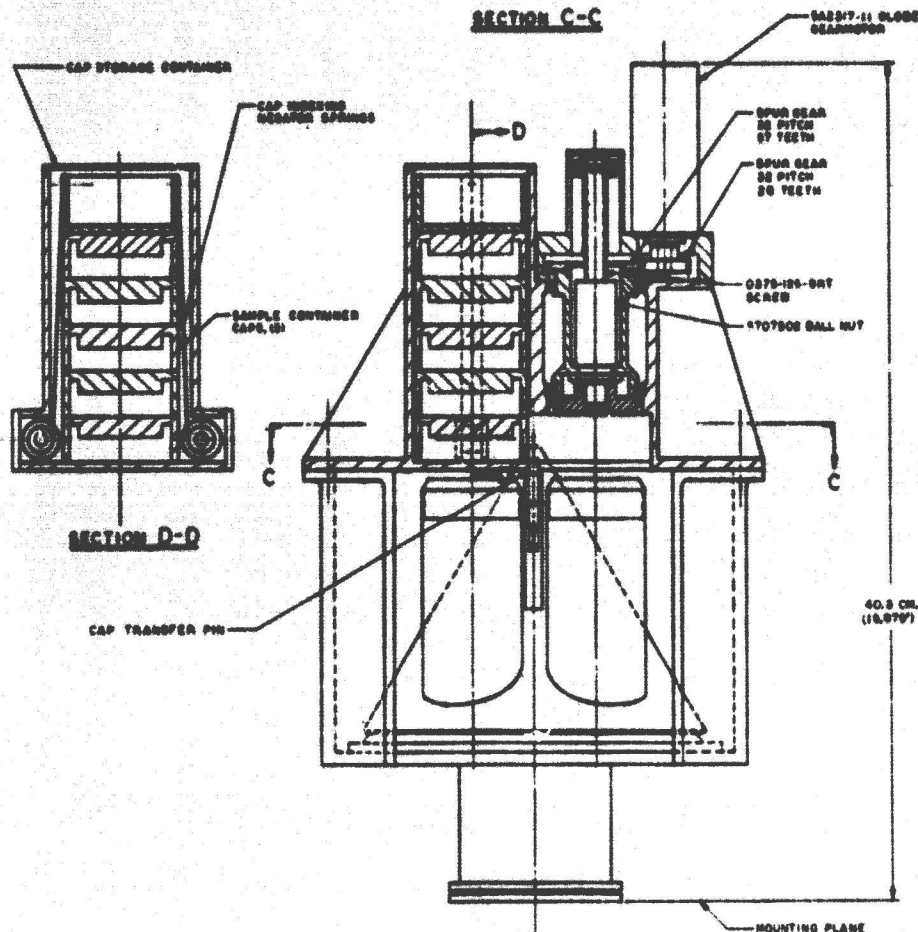


EXCEPT DRG PER MIL-STD-100 UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES AND ARE AFTER PLATING		DRAWN BY KYRIAS		DEPT 0485	DATE 12-4-79	MARTIN MARIETTA CORPORATION DENVER DIVISION POST OFFICE BOX 179 DENVER, COLORADO	
CHECKER STRESS ENGR WT ENGR MATL ENGR RELIABILITY QP ENGR PROJECT		TOLERANCES ON DECIMALS FRACTIONS X ANGLES .21/32 .21 .03 .010 .21/2° MACHINED SURFACES MIL-STD STATUS INTERCHANGEABLE REPLACEMENT UNCONTROLLED		CUST APPRVTY		ROCK CORE DRILL EXCHANGE MECHANISM	
SEE 04236		CODE IDENT NO MSR 120200		SCALE FULL		SHEET 1 OF 1	

FOLDOUT FRAME

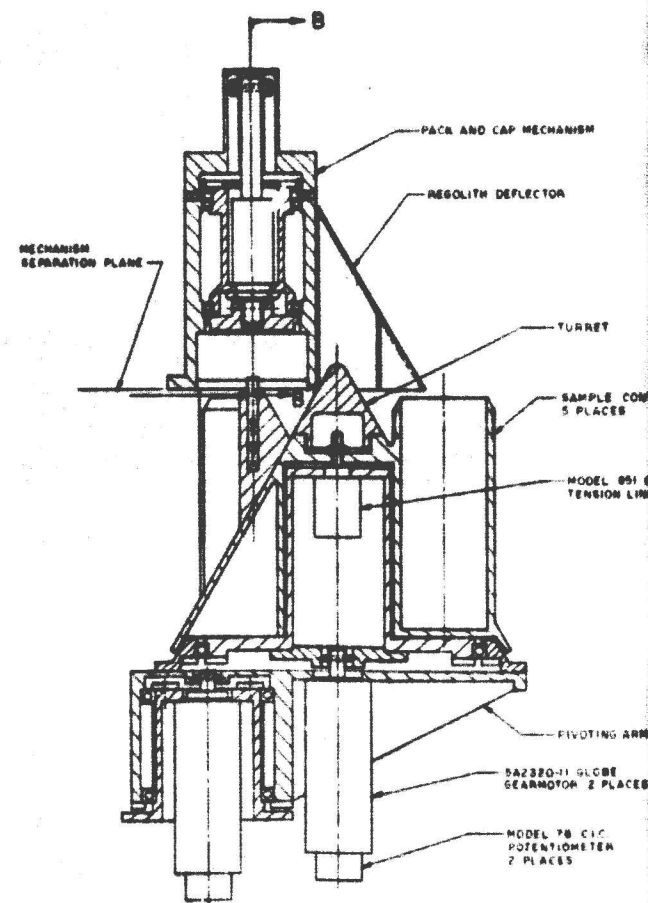
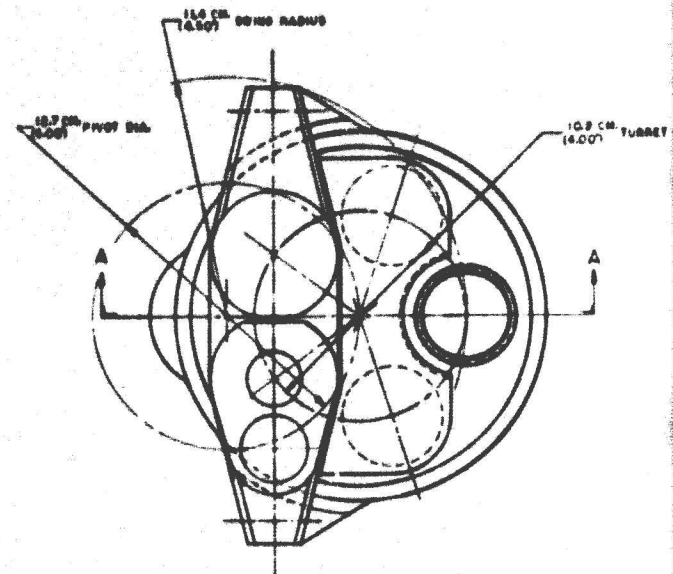


SECTION C-C

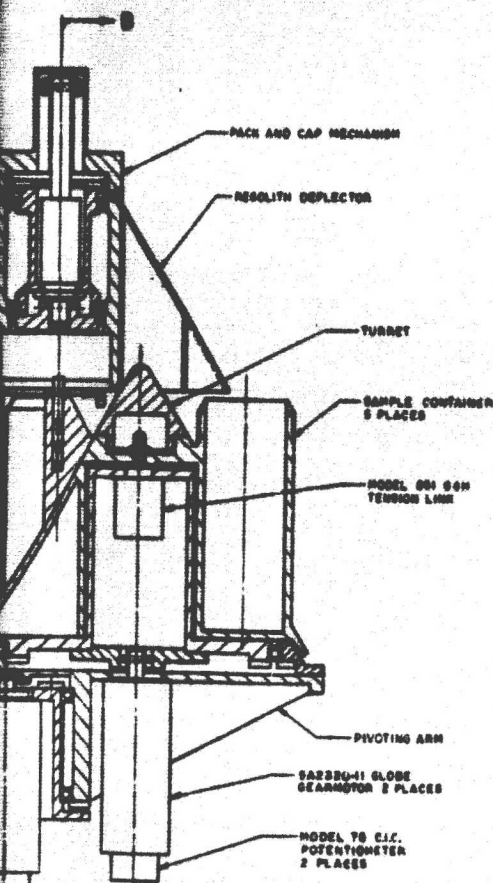
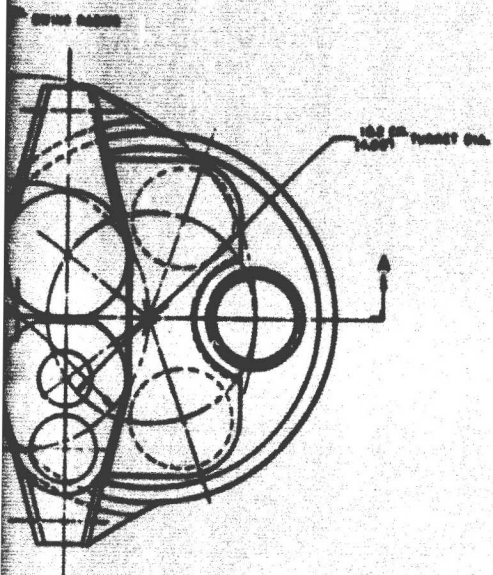


SECTION B-B

FOLDOUT FRAME



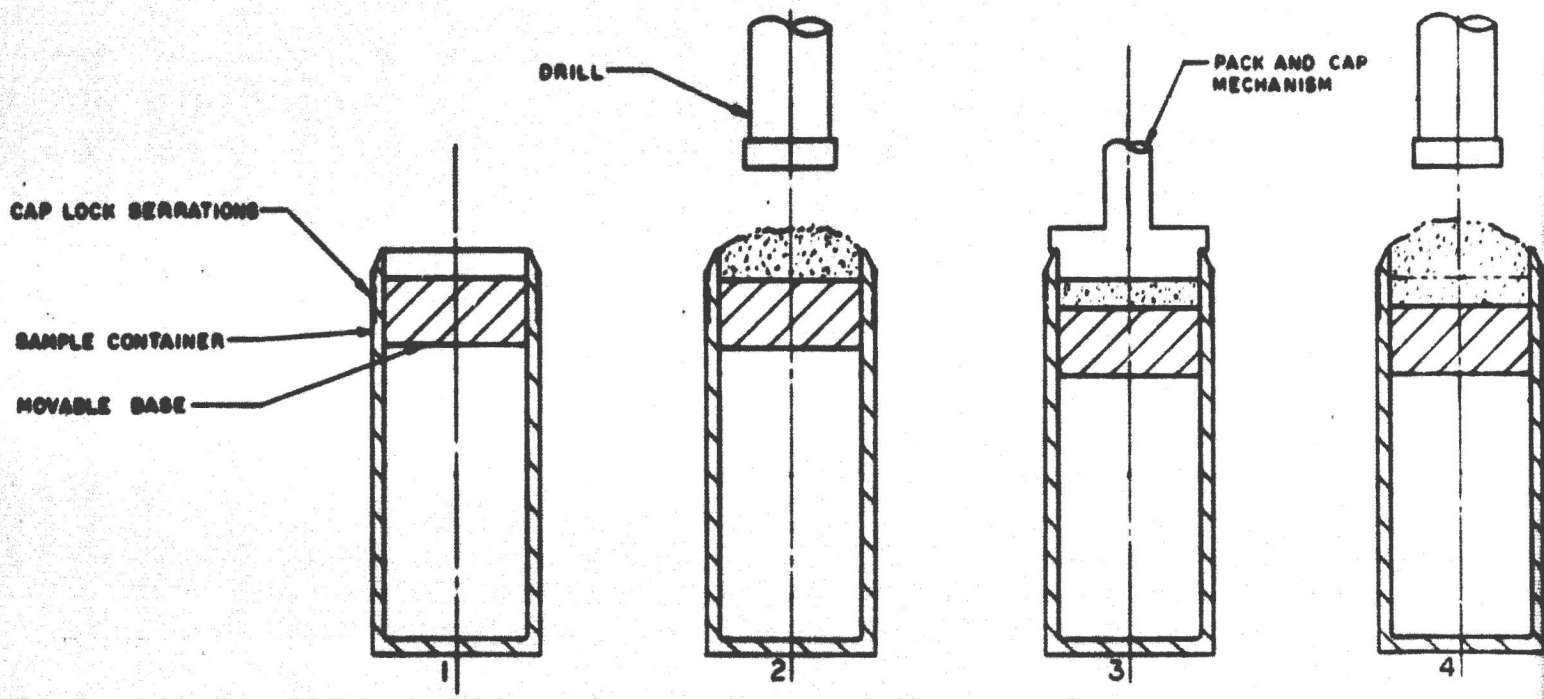
SECTION A-A



SECTION A-A

FOLDOUT FRAME

FORM NO. 10-10-10		DATE 12-8-70		REVISIONS	
PROJECT NO. 0485		SUBJECT		REGOLITH SAMPLE HANDLING SYSTEM (RSHS)	
DESIGNED BY		CHECKED BY		APPROVED BY	
DRAWN BY		CALCULATED BY		TESTED BY	
MATERIALS		FINISHES		TOLERANCES	
QUANTITY		UNIT PRICE		TOTAL PRICE	
0485		MSR-130000			

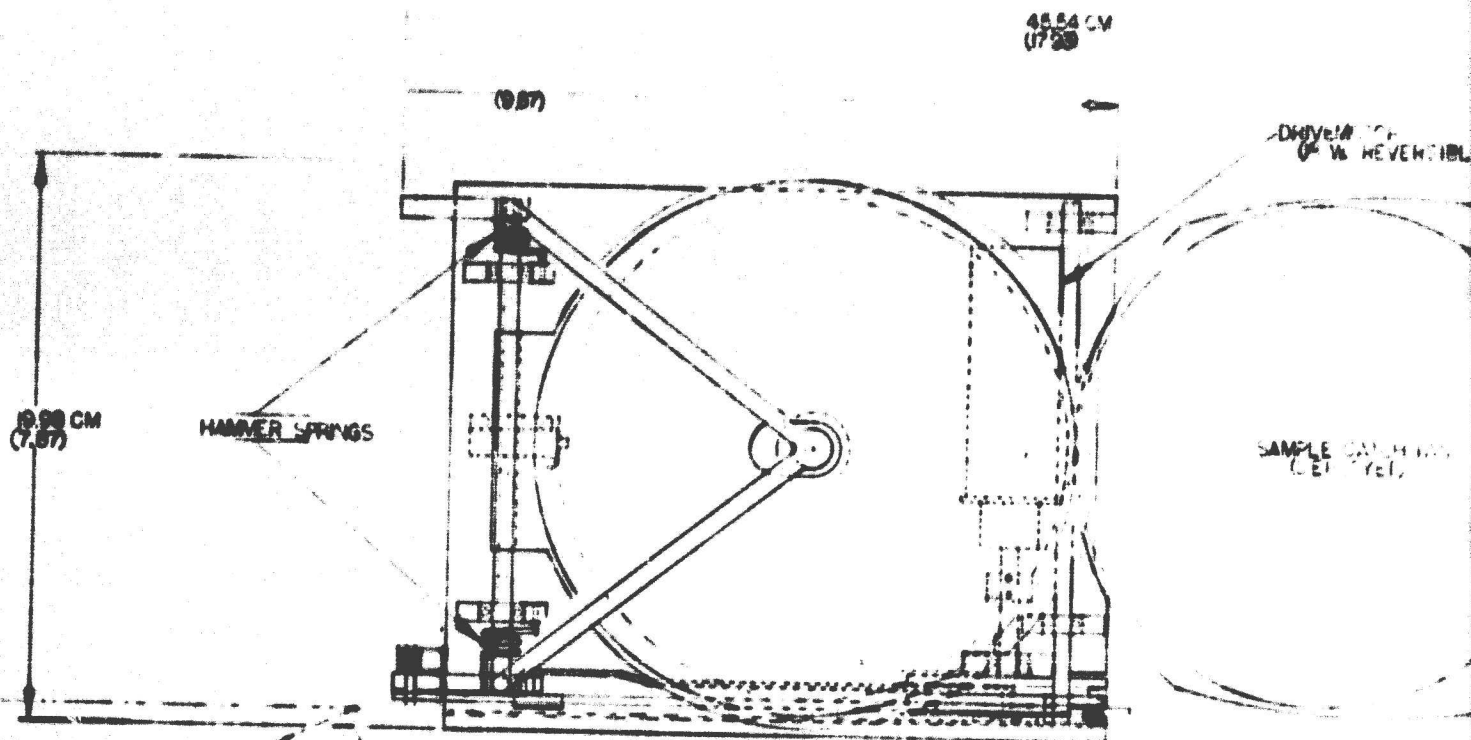


EOLDOUT FRAME

CAP

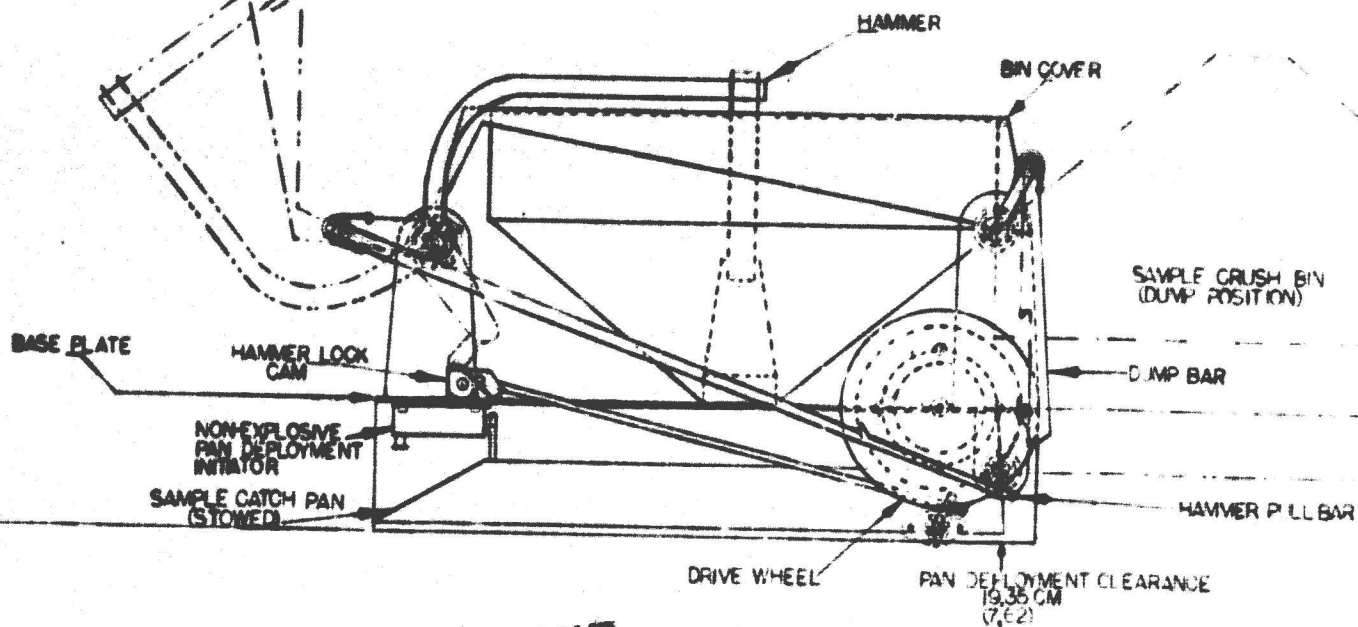
HOLDOUT FRAME

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION 1401 AIRPORT BLVD WASHINGTON, D.C. 20546 JAN 20 1970		AIR MAIL 100		AIR MAIL 100	
TO: DIRECTOR, NASA FROM: DIRECTOR, NASA		TO: DIRECTOR, NASA FROM: DIRECTOR, NASA		TO: DIRECTOR, NASA FROM: DIRECTOR, NASA	
SUBJECT:		SUBJECT:		SUBJECT:	
DATE:		DATE:		DATE:	
TIME:		TIME:		TIME:	
LOCATION:		LOCATION:		LOCATION:	
COMMENTS:		COMMENTS:		COMMENTS:	
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TITLE:		TITLE:		TITLE:	
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ATTACHMENTS:		ATTACHMENTS:		ATTACHMENTS:	
REMARKS:		REMARKS:		REMARKS:	
SPECIAL INSTRUCTIONS:		SPECIAL INSTRUCTIONS:		SPECIAL INSTRUCTIONS:	
APPROVAL:		APPROVAL:		APPROVAL:	
DATE:		DATE:		DATE:	
TIME:		TIME:		TIME:	
LOCATION:		LOCATION:		LOCATION:	
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SPECIAL INSTRUCTIONS:					



ORIGINAL PAGE IS
OF POOR QUALITY

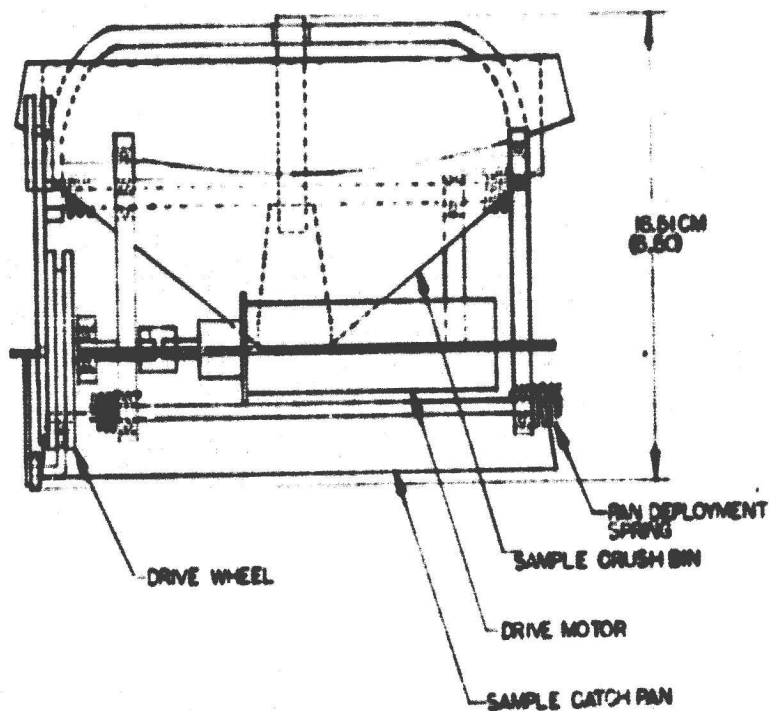
NORMAL OPERATING
CLEARANCE
30.63 CM
(12.05)



FOLDOUT FRAME

OPERATION
(ON & REVERSIBLE)

SAMPLE CATCH PAN
(DEPLOYED)



SAMPLE CRUSH BIN
(DUMP POSITION)

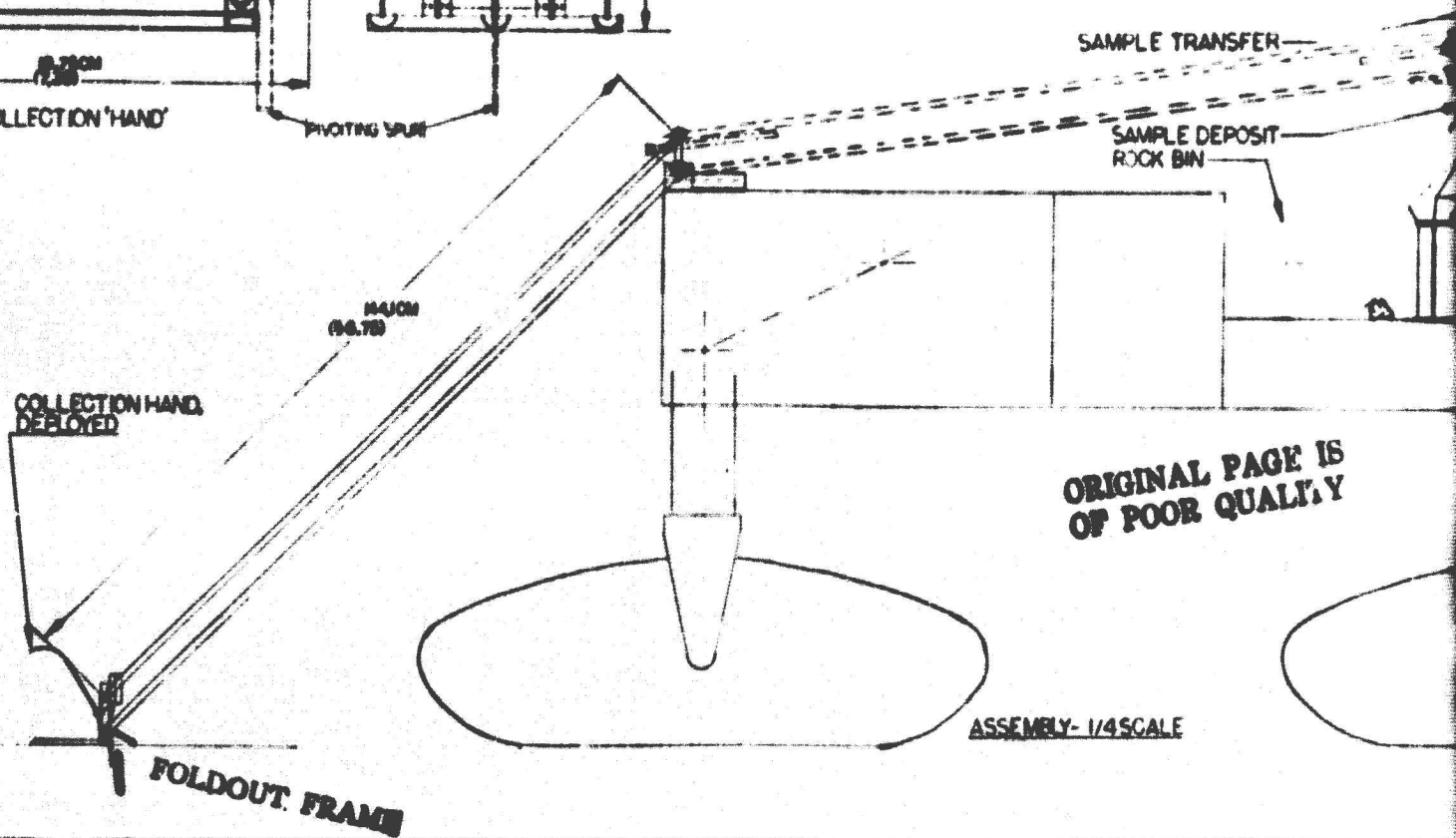
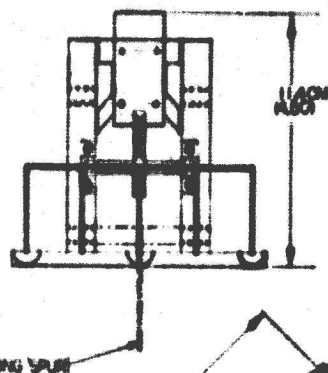
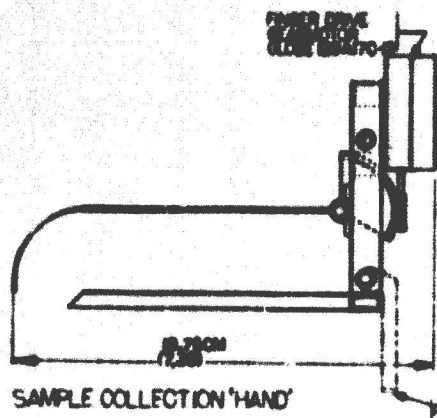
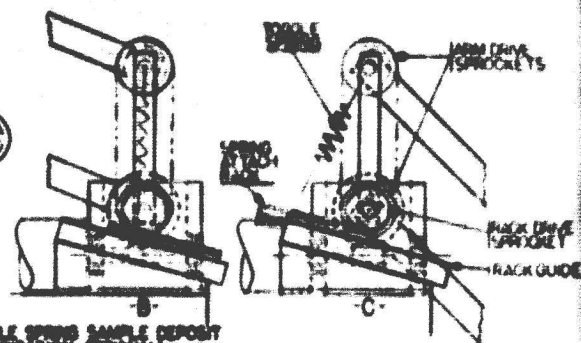
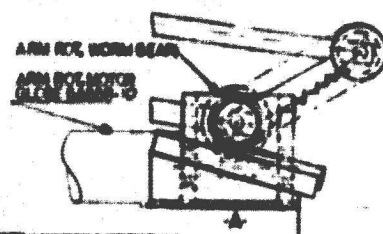
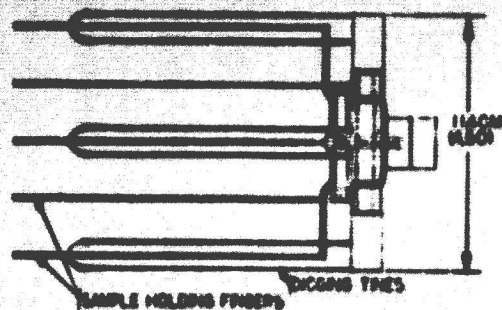
DUMP BAR

HAMMER PULL BAR

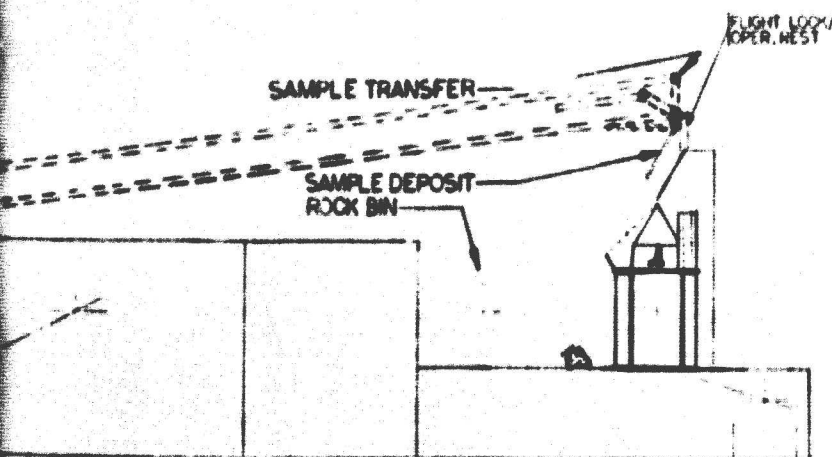
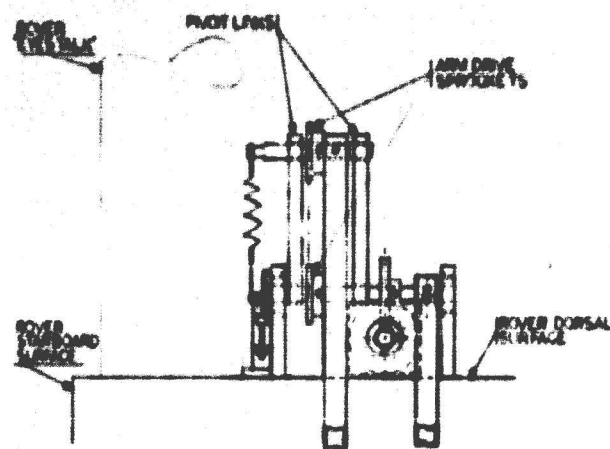
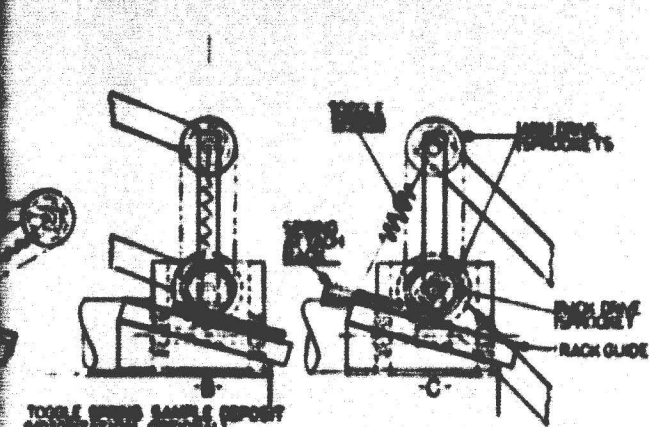
CLEARANCE

2 **EOLDOLT FRAME**

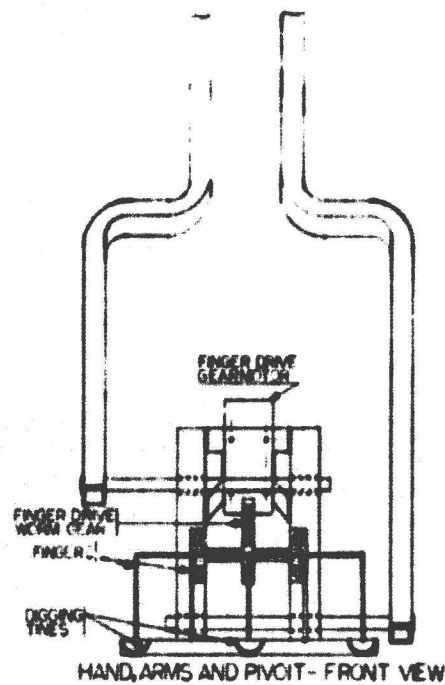
ELEVATION 0485 2-17-80	
	LANDER MOUNTED ROCK BREAKER SYSTEM
	MSR 200 000
FULL	TOP



ORIGINAL PAGE IS
OF POOR QUALITY



ORIGINAL PAGE IS
OF POOR QUALITY

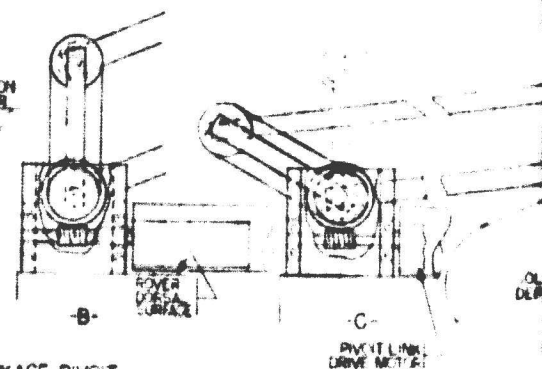
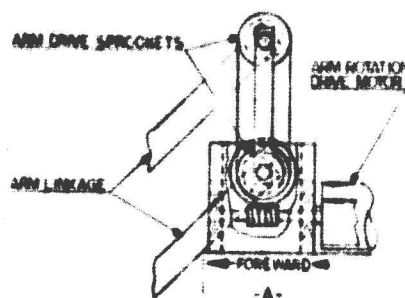
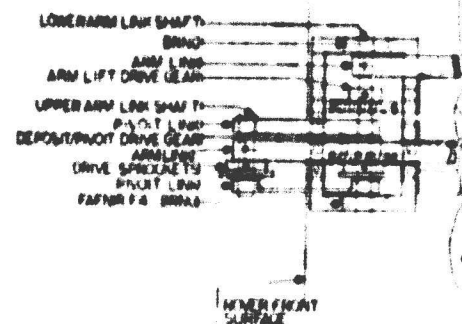


COLLOUT FRAME

ASSEMBLY - 1/4 SCALE

1/4 SCALE 0-100 10-12-50	ROVER SURFACE SAMPLE COLLECTION SYSTEM - GENERAL ARRANGEMENT - MSR-300000
--------------------------------	--

POWER STANDING SURFACE
TWO STALL PER STALL BASE

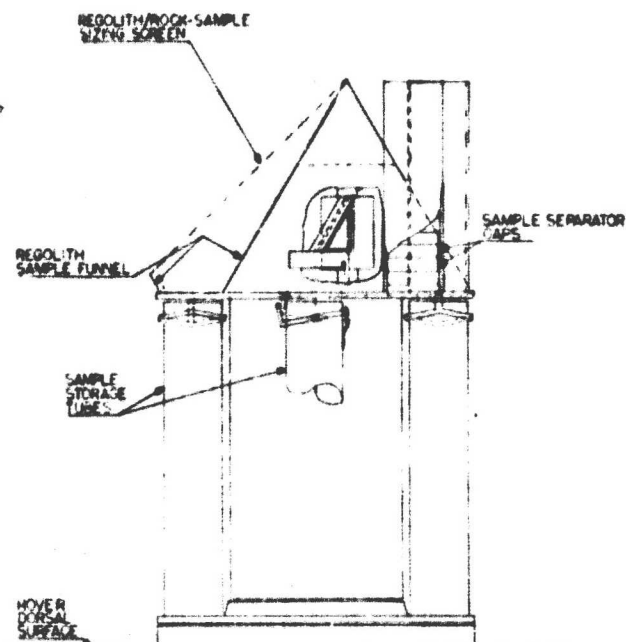
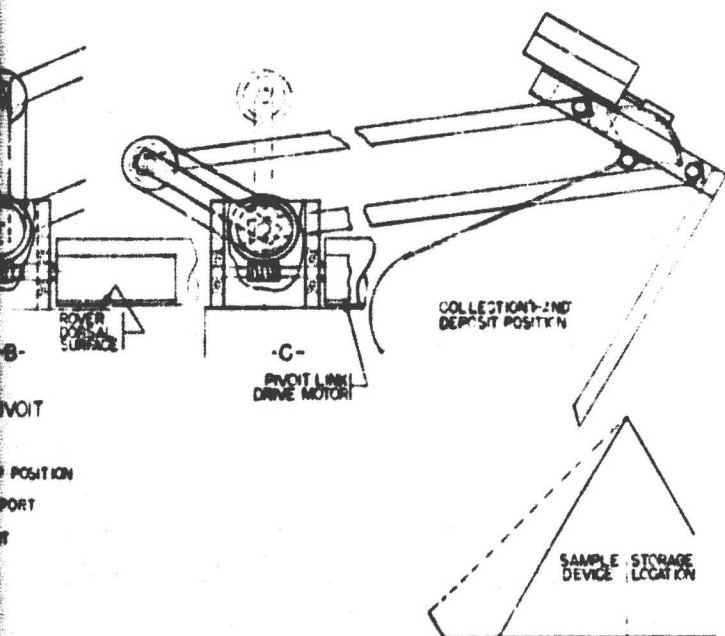
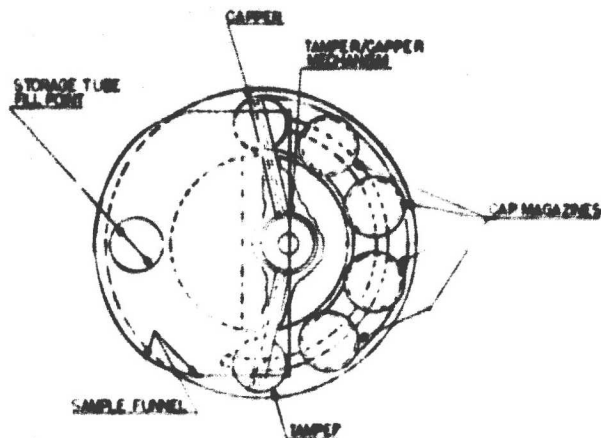
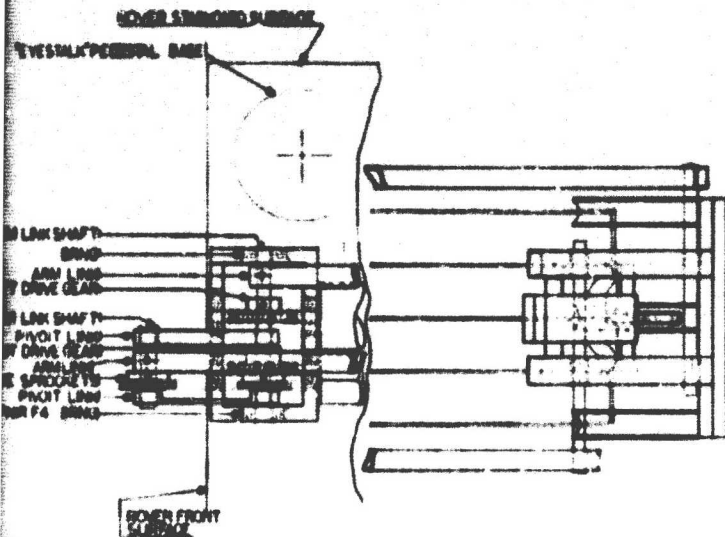


A-SAMPLE PICKUP POSITION
B-SAMPLE TRANSPORT
C-SAMPLE DEPOSIT

**SAMPLE COLLECTION 'HAND'
PICKUP POSITION**

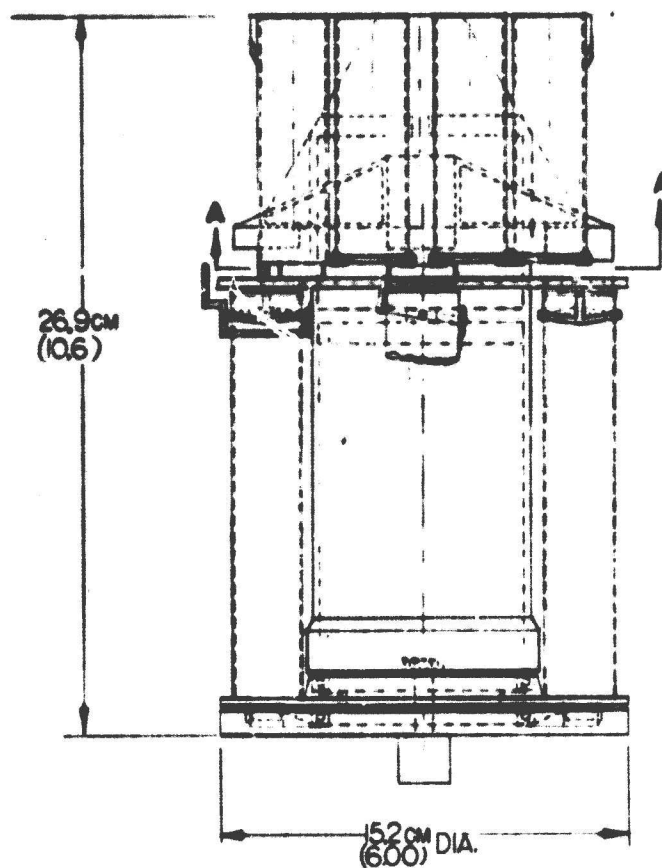
FOLDOUT FRAME

ORIGINAL PAGE IS
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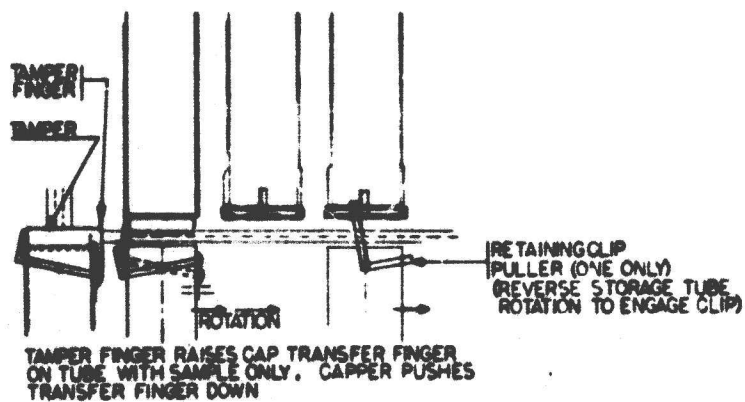


TENSION LINK RELEASE DEVICE
REGOLITH SAMPLE STORAGE DEVICE **BOLDOUT FRAME**

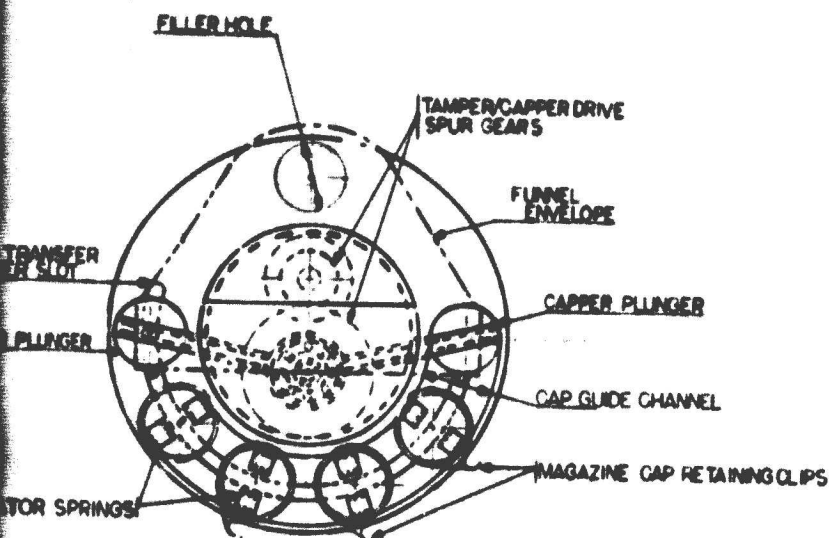
USCARS 485-0718	SAMPLE COLLECTION HAND
	MSR 310.000
1/2/71	1/2/71



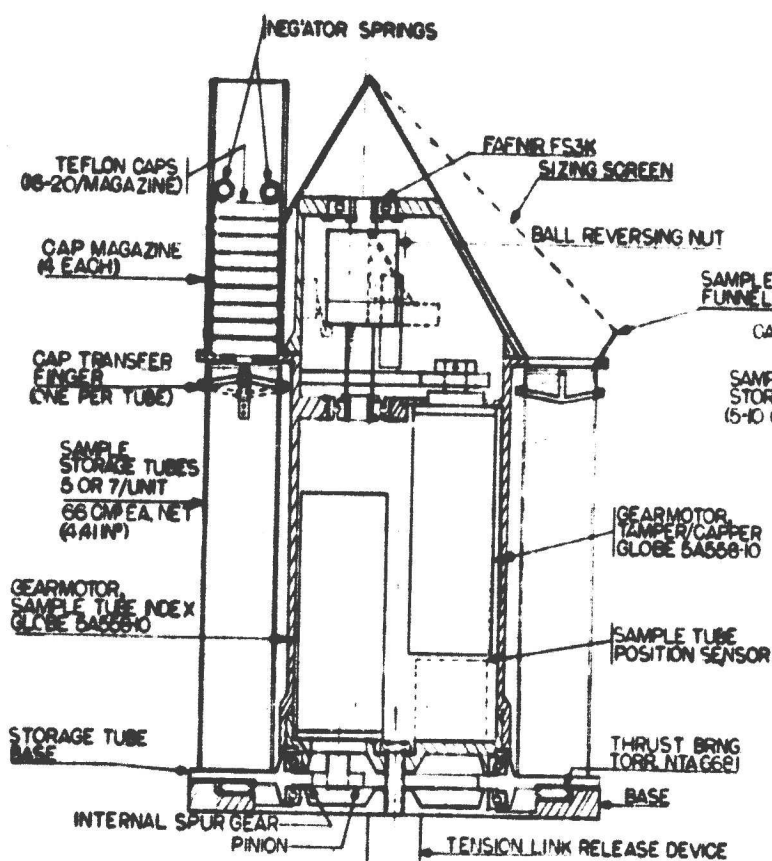
REAR VIEW



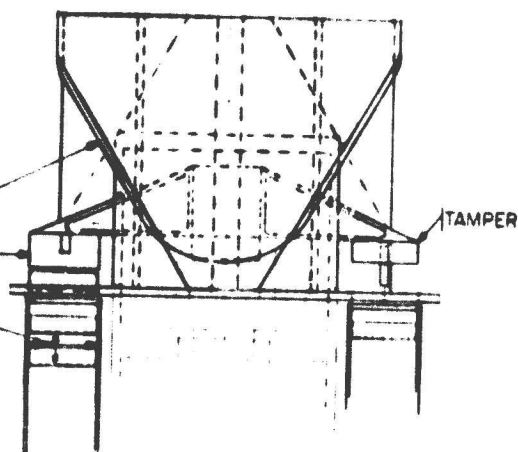
TAMPER/CAP TRANSFER DETAIL



VIEW A-A



REGOLITH SAMPLE STORAGE DEVICE



FRONT VIEW

ORIGINAL PAGE IS
OF POOR QUALITY
FOLDED FRAME

REGOLITH SAMPLE STORAGE	
MSR - 320000	
DATE FULL	1 of 1